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DETAILED FINAL REPORT OF RESEARCH ON
HIGH-SPEED ROTARY-FIXED WING AIRCRAFT

VOLUME IX

AERODYNAMIC CHARACTERISTICS OF A TWO-BLADED,
EIGHT-FOOT ROTOR MODEL AT HIGH TIP-SPEED RATIOS
AS MEASURED IN THE UWAL WIND TUNNEL

OFFICE OF NAVAL RESEARCH, AMPHIBIOUS BRANCH
PROJECT NR 250-C01 CONTRACT N9cnr-21901

Report 1975

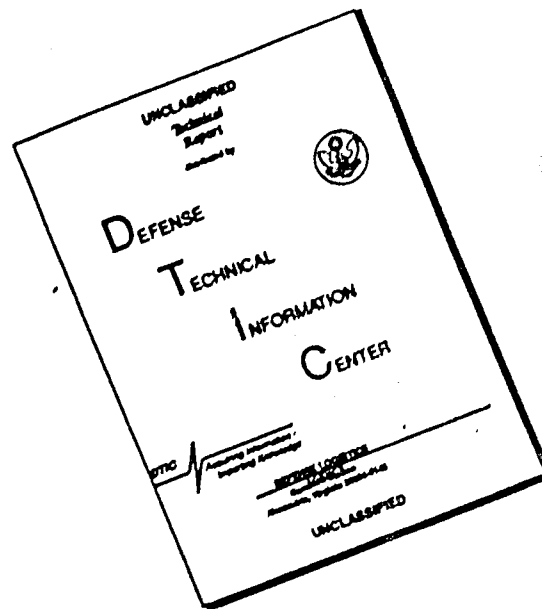
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DETAILED FINAL REPORT OF RESEARCH ON
HIGH SPEED ROTARY-FIXED WING AIRCRAFT

VOLUME IX

AERODYNAMIC CHARACTERISTICS OF A TWO-BLADED,
EIGHT-FOOT ROTOR MODEL AT HIGH TIP-SPEED RATIOS
AS MEASURED IN THE WIND TUNNEL

SUBMITTED UNDER Contract N9c-01 to the Office of Naval Research,
Amphibious Branch, Project NR 250-001

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1.0 SUMMARY

The results of two model test programs investigating the aerodynamic characteristics of a two bladed, see-saw rotor in the range of very high tip-speed ratios are presented in this report. This experimental work was done under contract for the Office of Naval Research and is the first portion of a broad program for investigating the characteristics of a rotor-fixed wing type of aircraft.

This report presents data for the rotor operating in the range of advance ratios from $\mu = 0.5$ to $\mu = 3.0$.

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2.0 INTRODUCTION

Early in 1949 a contract was entered into by the Office of Naval Research and McDonnell Aircraft Corporation for research into the problem of the rotor-fixed wing aircraft configuration. It was held that in order to accomplish high level flight speed of the order of 300 to 400 miles per hour, it would be necessary to have the rotor operate at tip-speed ratios very much higher than are conventionally used in helicopters and autogyros.

Consequently, the test program reported herewith was undertaken. The rotor model used was a two-bladed, see-saw type of rotor which was built from a salvaged rotor of the XL-20, "Little Henry", helicopter. The diameter of rotor was reduced and a special hub mounting was devised for mounting the rotor in the twelve foot UMAL wind tunnel at the University of Washington, Seattle, Washington. The prototype rotor was postulated as a pressure-jet type of rotor having burners at the blade tips. To simulate the drag of such tip-burners, small spheres of various sizes were attached to the tips of the model blades.

The first series of tests with this rotor during July, 1949, clearly demonstrated the possibility of using a rotor at very high advance ratios where the efficiency of the rotor is considerably improved over the low advance ratio operation. However, it also became clear that the rotor was quite sensitive to small changes in rotor attitude.

After this first series of tests, the model was modified to eliminate most of the drag of the blade hub fittings which proved objectionable in the previous tests. This entailed reducing the diameter of the rotor slightly and constructing a lens-shaped fairing for the rotor hub. Further, a device

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was designed for automatic control of the rotor attitude which was to govern the speed of the rotor.

The second series of tests was then conducted in the UWAL wind tunnel during October, 1949. These tests covered the high range of tip-speed ratios ($\mu = 2.5$ to $\mu = 2.5$) and a large range of blade pitch angles ($\theta = +3.0^\circ$ to -4.0°) for autorotation and for both accelerating and decelerating torque applied to the rotor. The aerodynamic characteristics of the rotor as determined by these tests were in reasonable agreement with the characteristics as determined theoretically in Reference 1.

The governor, while capable of stabilizing the rotor speed for small attitude changes, would require major modifications in order to correct larger attitude changes.

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3.0 DISCUSSION

3.1 Purpose of The Tests - The purpose of the first series of tests was to investigate the feasibility of operating a rotor at unconventionally high advance ratios and to provide preliminary data required for a later and more complete test program.

The second series had the following purposes:

- a. Check the operation of the automatic rotor attitude control.
- b. Determine the aerodynamic characteristics of the modified rotor model without hub fairing.
- c. Determine the influence of the lens-shaped hub fairing.

3.2 Test Equipment -

3.2.1 The Model -

3.2.1.1 First Series of Tests - The rotor model used in the first series of tests was a rotor which had been salvaged from the XH-20 "Little Henry" helicopter and modified for use in the wind tunnel (See Figures 1 and 2). The outer portions of the blades were removed to reduce the diameter to eight feet. Provision was made for mounting small spheres at the tips of the blades to simulate the effect of tip-jet units (See Figure 3). The hub was modified to allow the installation of a small electric motor for providing accelerating and decelerating torques to the rotor; an electric tachometer generator was also incorporated. Figure 4 shows the hub mechanism and the rotor control panel is shown in Figure 5.

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3.2.1.2 Second Series of Tests - For the second series of tests the model was modified somewhat. The hub fittings for the blades were greatly reduced in size to eliminate most of their drag (See Figure 6 and 7). This necessitated reducing the rotor diameter from eight feet for the original model to 7.58 feet. A lens-shaped fairing was designed to cover the blade hub fittings (See Figures 6 and 7).

A rotor attitude control governor was incorporated for stabilizing the rotor in the high advance ratio range. This governor was a modified Curtiss electric propeller governor which was driven by a flexible shaft from the rotor and stabilized the rotor speed by energizing an electric linear actuator which varied the rotor attitude in the wind tunnel. The model with the governor and the necessary control equipment is shown in Figure 8.

3.2.1.3 Model Data

	<u>First Series</u>	<u>Second Series</u>
Rotor diameter, feet	8.00	7.58
Number of blades	2	2
Blade chord, inches	6.2	6.2
Blade planform	Rectangular (extends from 1.4 ft. radius to 4.0 ft. radius.)	Rectangular (extends from 0.54 ft. radius to 3.79 ft. radius.)
Solidity Ratio	.082	.087
Blade Twist	None	None
Airfoil section	NACA 0013	NACA 0013
Rotor type	See-saw blades	See-saw blades

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3.2.2 Instrumentation

3.2.2.1 Standard Wind Tunnel Instrumentation - The standard wind instrumentation was used to measure three components in addition to the tunnel speed:

- a. lift
- b. drag
- c. yawing moment (a measure of the torque of the rotor)

Figure 3 shows the instrumentation on the photo-panel for the tunnel balance system. The balance is capable of measuring six components but only the three listed above were of interest in these tests. The instruments shown in Figure 3 are as follows:

1. Rotor RPM indicator, showing double rotor RPM
2. Angle of attack of rotor,
3. Clock
4. Angle of yaw, was zero for all tests
5. Drag force, switch on left side indicates sign of drag force, switch on right side gives the total range of instrument scale in pounds
6. Lift force, switches to left and right same as before
7. Side force, positive if to the right, seen in upwind direction, switches to left and right same as before
8. Pitching moment positive if tail heavy, around the moment center, which is 5.8" below the hub center. Switches to left and right same as before, except that switch on right side gives the total range of instrument scale in inch pounds.
9. Rolling moment, switches to left and right same as before

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10. Yawing moment, positive if clockwise seen from above, which is an accelerating air moment for the rotor, switches to left and right same as before.
11. Dynamic pressure deviation from Q_0 value as indicated in the upper right corner of the panel.
12. Air temperature indicator
13. Barometric pressure indicator

3.2.2.3 Special Instrumentation for the Rotor Model - Extra instru-

ments were required for the rotor model. These were:

- a. rotor speed indicator (indicated 2×10^3 RPM and was connected in parallel with the tachometer on the photo panel).
- b. rotor driving motor ammeter

These instruments were located on the rotor control panel shown in Figure 5.

In addition, a special protractor was employed to measure the rotor tip-path plane angle of inclination. This angle was observed visually using the device shown in Figure 10.

3.3 Operating Limitations -

3.3.1 First Series of Tests -

3.3.1.1 See-saw Angle Limitation - (approximately $\pm 12^\circ$) Under some test conditions this limitation was difficult to observe and the blades hit the stops several times, leading to heavy vibrations and to destruction of safety flexures in the tunnel balance system.

3.3.1.2 Rotor Angle of Attack Limitation - The upper limit of rotor angle of attack was given by interference with the fairing around the center

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portion of the model, approximately $+15^{\circ}$. The lower limit of α was given by operational limitations and varied with rotor pitch angle from $+2^{\circ}$ to $+6^{\circ}$.

3.3.1.3 Torque Limitation - The accelerating or decelerating torque limit was given by the electric motor and by the gears between rotor shaft and electric motor, approximately ± 20 inch pounds. Torques of $+12$ and -16 inch pounds, corresponding to ± 10 amps. in the armature of the electric motor could be maintained continuously throughout the tests.

3.3.1.4 RPM Limitations - A severe resonance of the model supports and balance system was encountered at about 600 RPM. Replacing the metal ring around the lower shaft bearing by a soft rubber ring lowered the resonance frequency somewhat, but running through the resonance range caused severe vibrations and the breaking of safety flexures in the balance system. The original metal ring was, therefore, reinstalled and the operating rotor RPM was limited to 500 RPM.

3.3.1.5 Tip Speed Limitation - The highest RPM for safe operation was 500 RPM which corresponded to a maximum tip speed of $\Omega R = 210$ ft./sec.

3.3.1.6 Advance Ratio Limitation - The highest advance ratio which was measured was $\mu = 3.0$. With increasing advance ratios the rotor became increasingly unstable and it was not possible to obtain steady conditions for high advance ratios.

3.3.1.7 Blade Pitch Angle Limitation - The instability mentioned before increased with blade pitch angle. The highest blade pitch angle for which

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fairly steady conditions could be reached up to $\mu = 2.0$ was $\theta = +5^\circ$. The limitation in negative blade pitch angle was $\theta = -5^\circ$ and was given by the maximum flapping angle of 212° of the blades which increases with blade pitch angle and with advance ratio, μ . The configuration with $\theta = -5^\circ$ could, for this reason, only be measured up to an advance ratio of $\mu = 1.5$. Within the measured blade pitch angle range from $+5^\circ$ to -5° no difficulties were encountered in starting the rotor.

3.3.2 Second Series of Tests - The limitations were about the same as those described above except for the RPM limitation. The severe resonance which was observed for the first model at 600 RPM was reduced to 450 RPM because of the greater elasticity of the blade root section. Most of the tests were conducted at below resonance rotor speeds. Some of the tests at above resonance rotor speeds and some tests which were inadvertently run in the resonance range resulted in breaking the flexures in the tunnel balance system.

3.4 Test Procedure

3.4.1 First Series of Tests - After a few preliminary runs to check out the apparatus, the following test procedure was adopted:

- a. Set the blade pitch angle.
- b. Install the tip-drag spheres if required for the particular test.
- c. Establish a nominal rotor speed of 375 rpm.
- d. Establish the proper tunnel speed to obtain the desired advance ratio.
- e. Take photo-panel picture and simultaneously observe and record the tip-path plane angle of attack.

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- f. Introduce an accelerating or decelerating torque as required and repeat (c), (d) and (e) above.

3.4.2 Second Series of Tests

3.4.2.1 Tests Without Automatic Rotor Attitude Control - The procedure for these tests was as follows:

- Set the blade pitch angle.
- Install the tip-drag spheres if required for the particular test.
- Establish a nominal rotor speed and tunnel speed in accordance with the following table:

	.5	.75	1.0	1.25	1.5	2.0	2.5
μ							
SR, mph	143	128	112	99.5	89.5	74.5	64
V, mph	74.5	96	112	124	134	149	160
$g \cdot \mu / \text{ft}^2$	14	23.5	32	39.5	46	56.5	65
RPM	550	475	415	470	330	275	235

The RPM was different for each advance ratio so as to obtain a constant tip speed at the advancing blade rather than a constant RPM as in the first test series. The constant tip speed tests give a more realistic picture of the rotor characteristics since the actual aircraft probably will operate under the same conditions. The tip speed at the advancing blade was chosen as 225 mph.

- Take photo-panel picture and simultaneously observe and record the tip-path plane angle of attack.
- Introduce an accelerating or decelerating torque as required and repeat (c) and (d) above.

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3.4.2.2 Tests With Automatic Rotor Attitude Control - The procedure for these governor tests was as follows:

- a. Set zero blade pitch angle
- b. Establish rotor and tunnel speeds in accordance with (c) of Section 3.4.2.1.
- c. Apply a sudden one degree rotor attitude disturbance.
- d. Observe the amplitude of the RPM oscillations and the time required for the disturbance to subside.

3.5 Test Results

3.5.1 First Series of Tests - The first series of tests was intended mainly as a preliminary investigation of the feasibility of operating a rotor at unconventionally high advance ratios. It was demonstrated that advance ratios of the order of 2.5 to 3.0 were possible so the second test series described below was planned to fully investigate the high advance ratio range.

No quantitative data are given for the first test series because they are of doubtful value as a result of the poorly designed hub which increased the drag of the rotor considerably and contributed essentially no lift.

3.5.2 Second Series of Tests -

3.5.2.1 Corrections to Photo-Panel Data -

a. α Correction:

The indicated values of α were within 0.1° of being identical with the actual values and no correction was necessary. The wind

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tunnel wall correction of α was in the order of 0.1° and, therefore, negligible.

b. Lift Correction -

The lift was corrected for the hub lift which was determined by tests without blades. The hub lift is approximately independent of the angle of attack of the rotor and of the rotor RPM and only dependent on the tunnel speed. The following values were used:

$$L' = L - L_H$$

where L_H (lb.)	=	0.5	0.9	1.2	1.5	1.5	1.9	2.2
for q (lb./ft ²)	=	14	23.5	32	39.5	46	56.5	65

The wind tunnel wall correction for the lift is negligible because of the small lift coefficient (maximum $C_L = 0.02$).

c. Drag Correction -

The drag was corrected for the hub drag as determined by tests without blades. The hub drag is approximately independent of the angle of attack of the rotor and of the rotor RPM and only dependent on the tunnel speed. The following values were used:

$$D' = D - D_H$$

where D_H (lb.)	=	1.7	2.8	3.8	4.7	5.4	6.7	7.7
for q (lb./ft ²)	=	14	23.5	32	39.5	46	56.5	65

The wind tunnel wall correction for the drag is negligible as for C_D and for the lift.

d. Torque Correction -

The yawing moment, M_y , is approximately equal to the rotor torque, since the shaft axis was inclined only a few degrees with respect to the vertical axis. The torque was corrected for the hub torque.

The following values were used:

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$$M_Y^0 = M_Y - M_{Y_H}$$

where M_{Y_H} (in.-lb.) = -0.8 -0.9 -0.9 -0.9 -0.9 -0.9 -0.9
for q (lb./ft.²) = 14 23.5 32 39.5 46 56.5 65

e. Lift to Drag Ratio Correction -

The lift to drag ratio of the rotor was corrected for rotor torque by using instead of the drag, D' , the value:

$$D'' = D' - \Delta D$$

where $\Delta D = \frac{M_Y'}{R}$ (R = rotor radius)

L/D'' is the equivalent lift to drag ratio and is usually locked upon as an appropriate efficiency figure for a rotor.

3.5.2.2 Transfer of Data to Coefficient Form - The force and moment measurements were converted into coefficient form by the following equations:

$$\Omega R, \text{ mph} = 0.135 \text{ RPM}$$

$$\mu = \frac{V_{\text{mph}}}{(\Omega R)_{\text{mph}}}$$

$$C_L = \frac{L'}{\pi R^2 q}$$

$$C_T = \frac{\mu^2 C_L}{2}$$

$$C_Q = - \frac{M_Y' \mu^2}{\pi R^3 q}$$

$$C_D = \frac{C_L}{(L'/D'')}$$

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3.5.5 Sample Plots of Data

3.5.5.1 Thrust Coefficient - Figure 11 shows the thrust coefficient, C_T , against α for zero tip drag and for a blade pitch angle, $\Theta = -1.5^\circ$. The slope of the $C_T - \alpha$ curve becomes very steep at higher advance ratios, μ . The blade loadings, (C_T/σ) , reach extraordinarily high values at high advance ratios. (C_T/σ) values up to 0.55 were measured. The autorotation curve indicates clearly the instability at higher advance ratios. Above $\mu = 1.25$ this curve is nearly vertical and small changes in α have a very large effect on the equilibrium advance ratio, μ ; that is, on the equilibrium RPM. Below $\alpha = 4^\circ$, no autorotation is possible.

3.5.5.2 Torque Coefficient - Figure 12 shows the torque coefficient, C_Q , plotted against α for zero tip drag and for a blade pitch of $\Theta = -1.5^\circ$. Positive C_Q corresponds to power input into the rotor, negative C_Q , to power output from the rotor. The dotted line refers to the autorotation with hub, and the ordinates of this curve represent the hub torque which was subtracted from the measured torque. The $C_Q - \alpha$ curves also become very steep at higher advance ratios, μ .

3.5.5.3 Tip-Path Plane Angle of Attack - Figure 13 shows the rotor plane angle of attack, α_R , plotted against α for zero tip drag and for a blade pitch of $\Theta = -1.5^\circ$. The $\alpha_R - \alpha$ curves increase their slope with μ , indicating a high sensitivity to small α changes.

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3.5.3.4 C_T , C_E , and C_R As Functions of μ - Figure 14 shows C_T , C_E , and C_R plotted against μ for $\theta = -1.5^\circ$ in autorotation. The flat α - μ curve for higher μ again indicates the unstable character of these conditions. ($\alpha_R - \alpha$) is the flapping angle of the blades which is quite moderate for $\theta = -1.5^\circ$.

3.5.3.5 Drag, Lift, and Lift-to-Drag Ratio A Function of μ - Figure 15 shows the lift to drag ratio, L/D , (called L'/D' in Section 3.5.2) the lift coefficient, C_L , and the drag coefficient, C_D , of the rotor without hub plotted against advance ratio, μ , for $\theta = -1.5^\circ$ in autorotation. The increasing L/D values and the decreasing C_L values with higher advance ratios indicate that from a point of view of performance at high speed large advance ratios are desirable.

3.5.3.6 Torque Coefficient For Various Blade Pitch Angles - Figure 13 shows the torque coefficient, C_Q , plotted against α for various blade pitch angles, θ , and for an advance ratio of $\mu = 1.5$. Note that a decrease in blade pitch in this region increases the decelerating torque, which is opposite to the effect of blade pitch changes in the helicopter flight condition. The rotor is less sensitive to α changes (more stable) at lower blade pitch angles.

3.5.3.7 Effect of Blade Angle on C_T , C_E , and C_R - Figure 17 shows the effect of blade pitch angle, θ , on thrust coefficient, C_T , on α , and on α_R for $\mu = 1.5$, in autorotation. The flapping angle ($\alpha_R - \alpha$) is zero for $\theta = -2.5^\circ$ and increases rapidly with negative θ .

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3.5.3.8 Effect of Blade Angle on (L/D) , C_L , and C_D - Figure 18 shows the effect of blade pitch angle, Θ , on lift-to-drag ratio, L/D , on C_L , and on C_D . While C_L and C_D decrease with negative Θ , the L/D ratio has a flat optimum at about $\Theta = -1.5^\circ$.

3.5.4 Tests With the Automatic Rotor Attitude Control - Because of several delays and required modifications of the test equipment the governor tests were reduced somewhat in scope. The tests were made for only one blade pitch setting, $\Theta = 0^\circ$, and for zero torque. Advance ratios of 0.5, 1.0, 1.5, and 2.0 were investigated.

It was found that the RPM oscillations damped out after two to three oscillation periods after a sudden one degree rotor attitude disturbance. But while the oscillations damped out quickly, the maximum RPM error was much too high (+ 25% for + 1° attitude change and -8% for - 1° attitude change).

3.5.5 Experimental Data - The complete data accumulated during the second series of tests is presented in Section 7.0.

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4.0 CONCLUSIONS

The second series of tests confirmed the results of the first series that anterotation of the VTO rotor at high advance ratios is very advantageous from a point of view of blade losses. The drag coefficient of the blade without hub, referred to the rotor disc area, is only 0.001 at $\mu = 2.0$. This means that a 50-foot rotor, suitable for a 20,000 pound rotor-fixed wing aircraft, would only represent the equivalent of two square feet parasite drag area. This drag is not totally parasitic because the rotor also produces a lift force up to 13 times greater than this drag. The over-sensitivity of all rotor characteristics with respect to rotor angle of attack changes should be mitigated because otherwise even moderate gusts would cause excessive flapping of the blades. These tests have been extended up to an advance ratio of 2.5, which corresponds to a flight speed of 380 mph with a tip speed at the advancing blade of 800 ft./sec. or to 340 mph with a tip speed of 700 ft./sec.

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MODEL _____

5.9 REFERENCES

1. Head, R. E.

The Results of an Analytical Study of
the Aerodynamic Rotor Characteristics
at High Tip-Speed Ratios. MAC Report
No. 1686, 12 May 1950.

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DATE 22 January 1951

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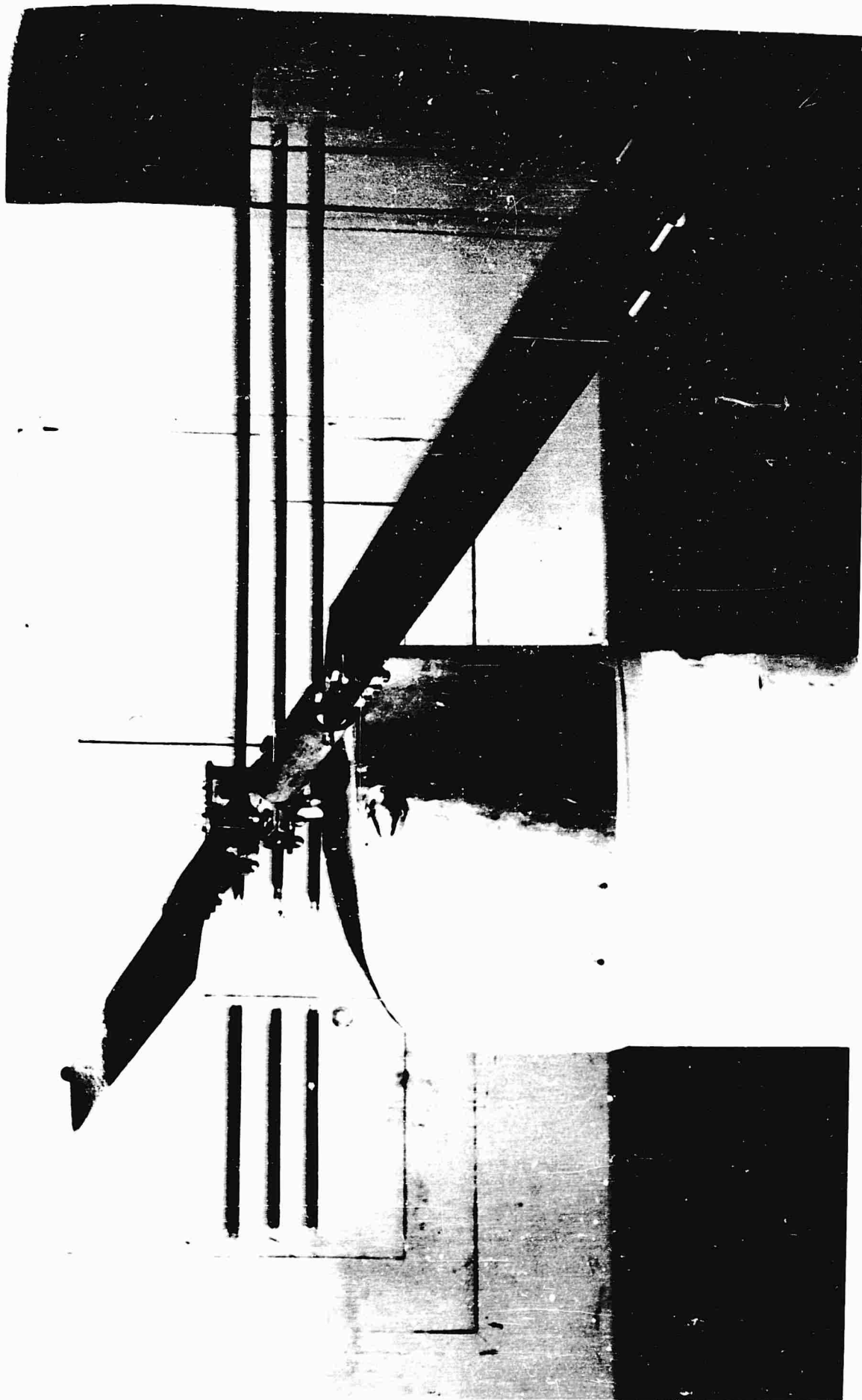
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6.0 PHOTOGRAPHS AND SELECTED
TEST RESULT GRAPHS

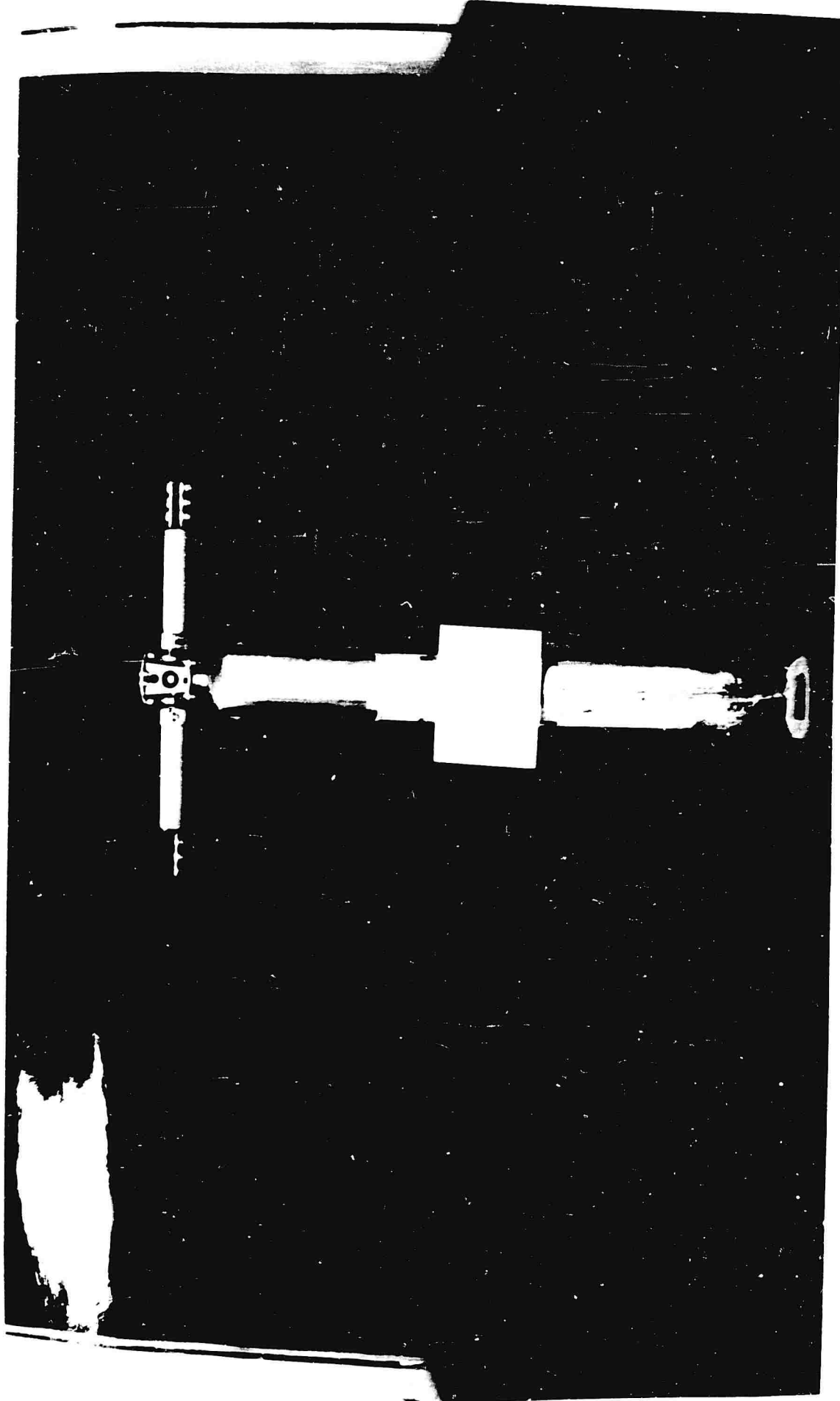
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D4E-19772-490-9

Figure 1
Side View of Model as Installed in the Wind Tunnel
(First Series of Tests)

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D4E-19772-490-8

Figure 2

Front View of Model as Installed in the Wind Tunnel
(First Series of Tests)

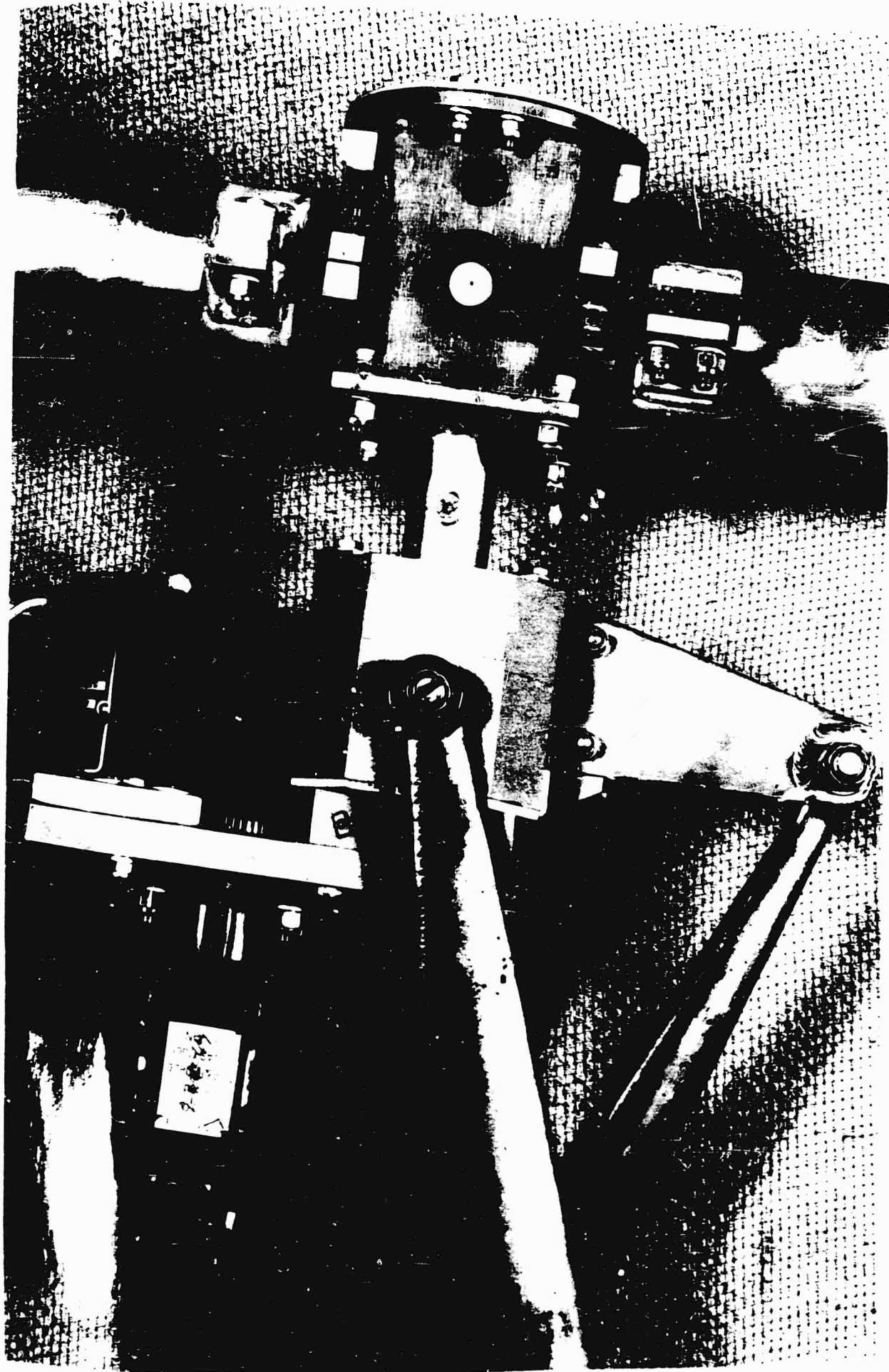
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D4H-13893

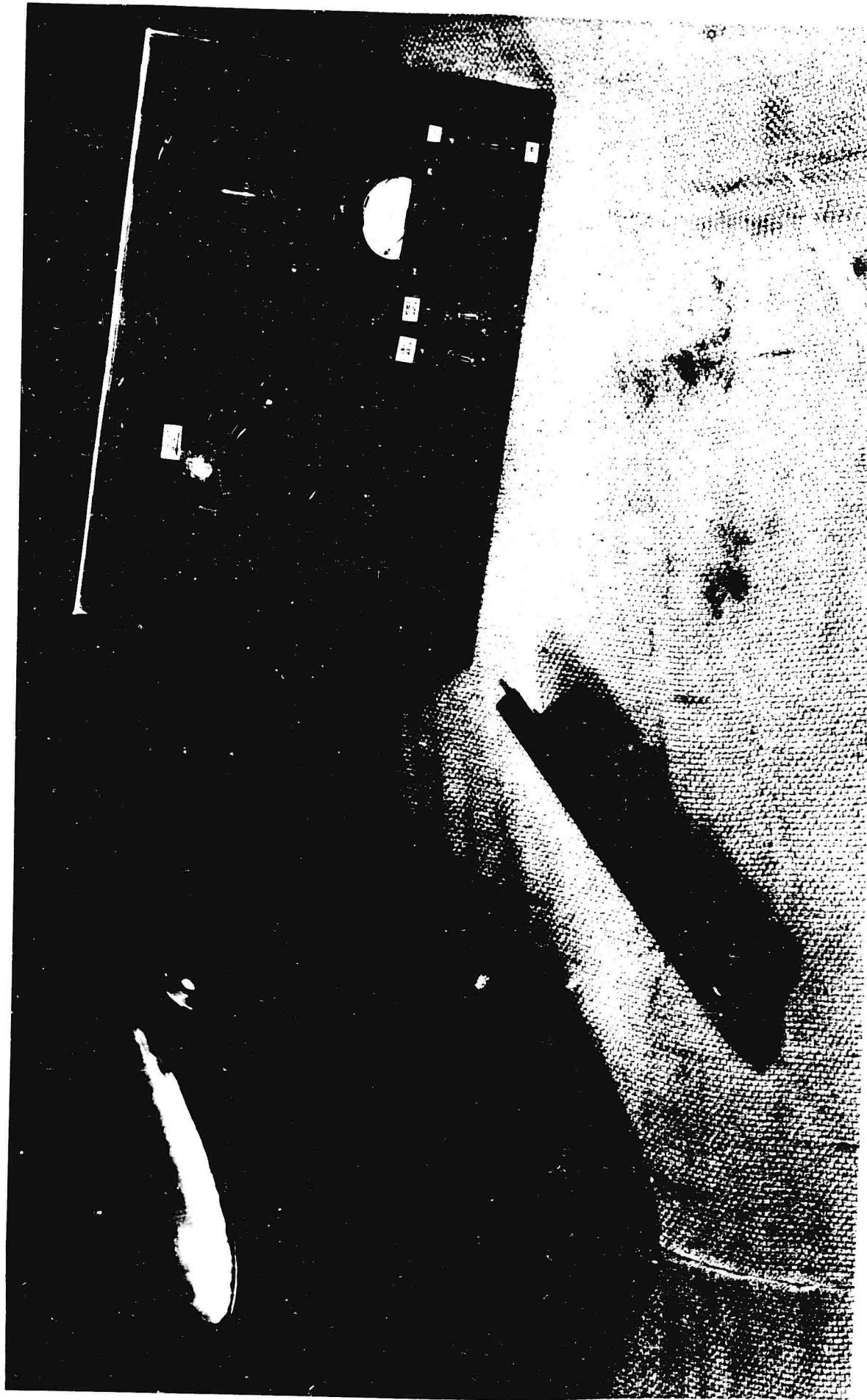
Figure 3
Blade Tip Spheres

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Report 1975
Negative No.
D4H-13896

Figure 4
Center Portion of Model Including Fork and Pitch Arm of Tunnel Equipment
(First Series of Tests)



Report No. 1975
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D4H-13895

Figure 5
Upper Fairing, Central Panel for Electric Motor for Model, and Blade
Pitch Measuring Fixture

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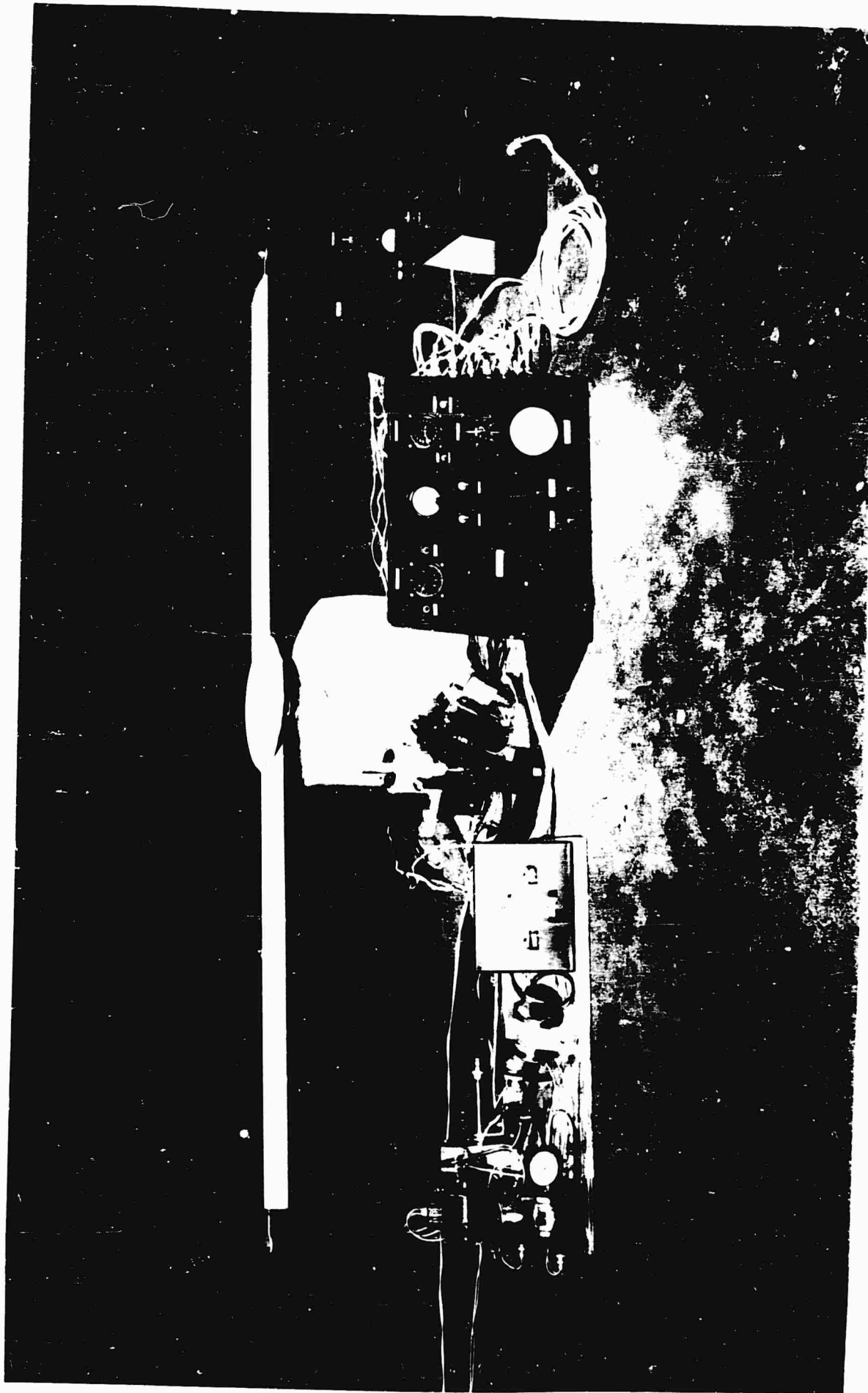
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NEGATIVE DAE-15435

FIGURE 6 - REVISED ROTOR MODEL WITH HUB-FAIRING
(SECOND SERIES OF TESTS)
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Figure 7
Revised Rotor Model With One Section of Hub Fairing Removed
(Second Series of Tests)

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Negative No.
D4E-15438

Figure 8
Revised Motor Model With Governor and Control Panels
(Second Series of Tests)

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7-20-49 | **REPORT NO. 309** | **FORK 5-L**
STRUT=S | **MCDONNELL VTO ROTOR MODEL #1**

CONFIG. RB.S.P

$\theta = 0^\circ$

$\alpha_R = 6.3$

$M = 1.0$

RUN 2

RPM = 500

AMPS = +10

P
 ΔL 0
 ΔD 0
 ΔM 0
 $q =$ 13

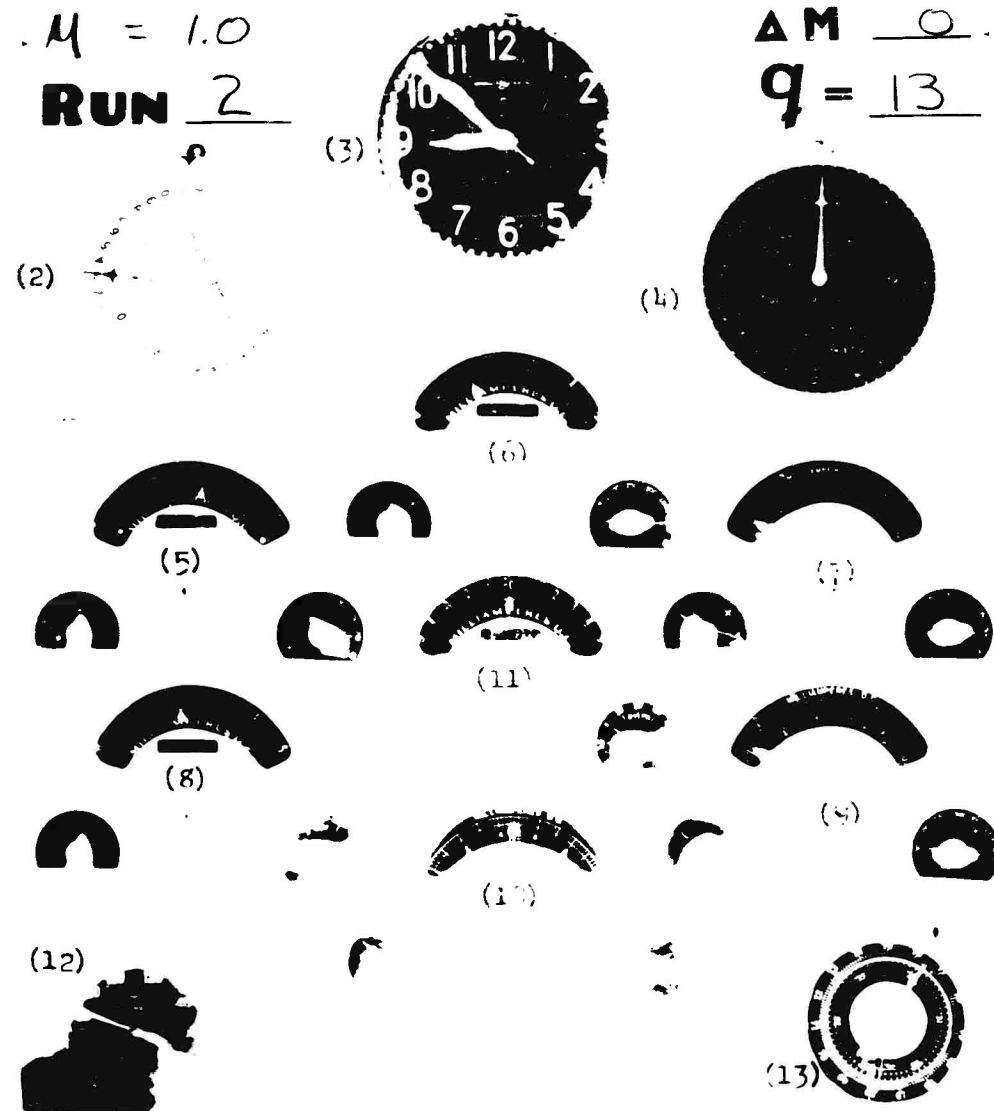


FIGURE 9. TYPICAL PHOTO-PANEL PHOTOGRAPH
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Figure 10
Device for Measuring the Attitude of the Rotor Tip Path Plane

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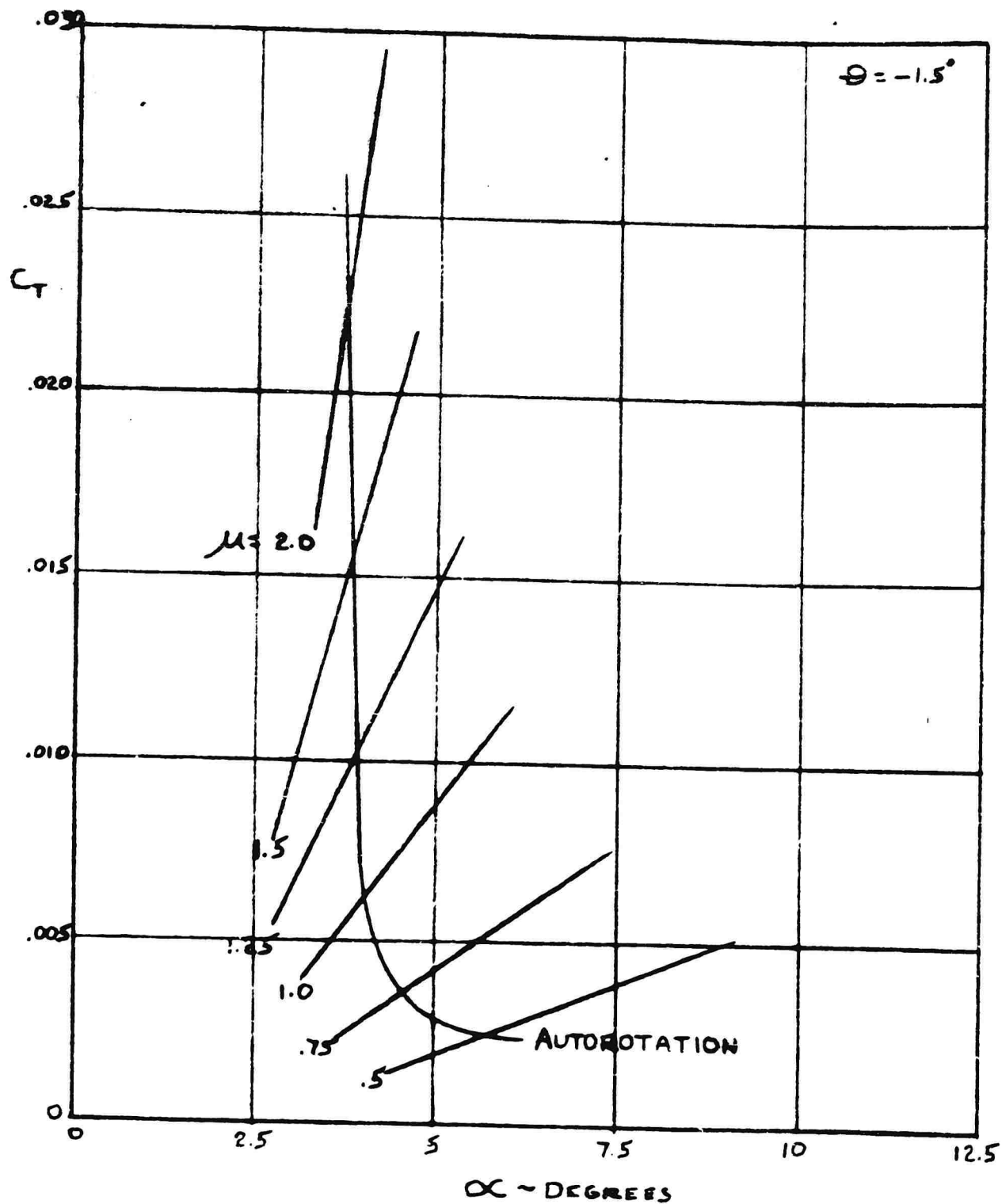


FIGURE 11

THRUST COEFFICIENT C_T PLOTTED AGAINST α FOR ZERO TIP DRAG
AND FOR BLADE PITCH $\theta = -1.5^\circ$

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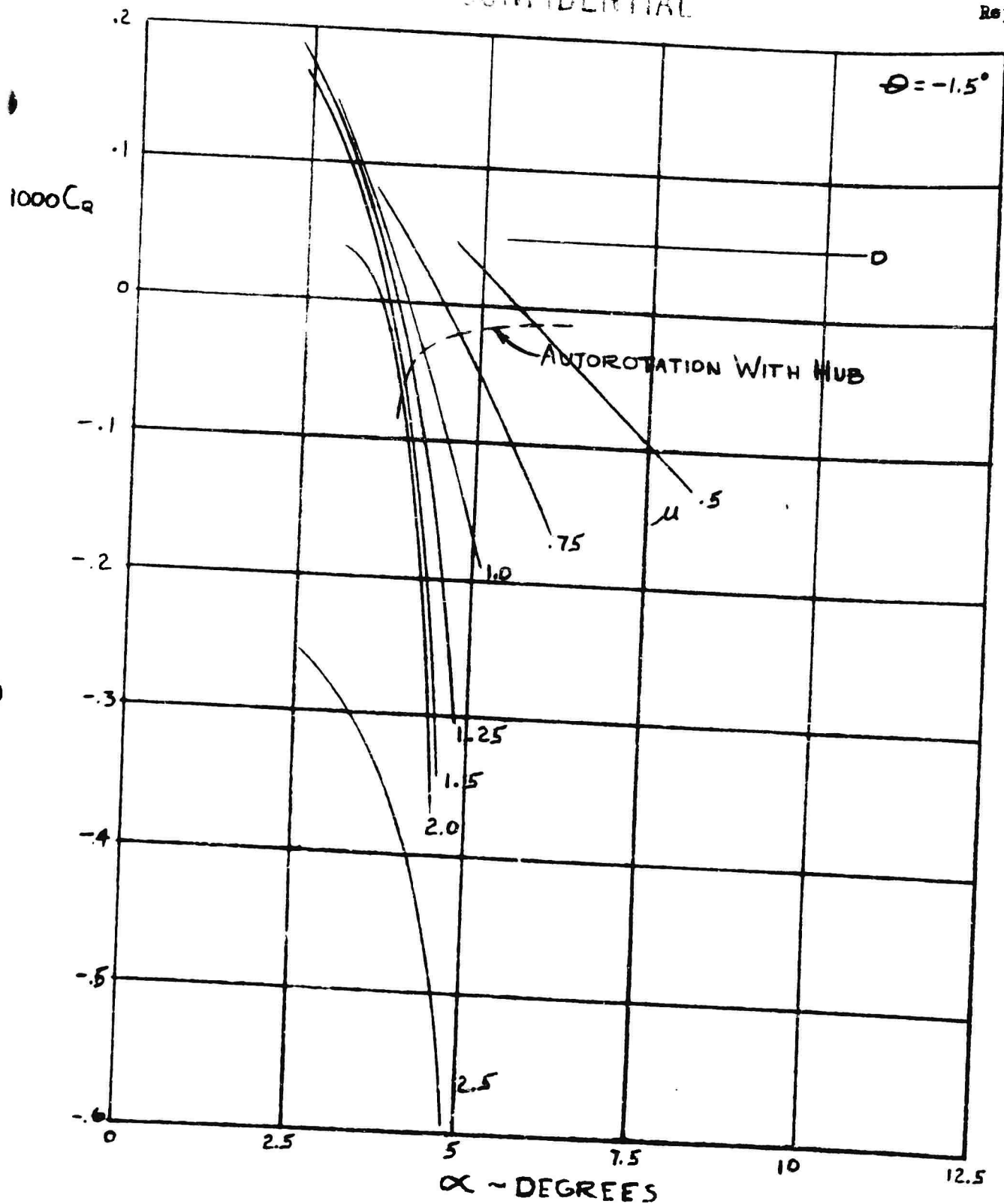


FIGURE 12

TORQUE COEFFICIENT C_q PLOTTED AGAINST α FOR ZERO TIP DRAG
AND BLADE PITCH $\theta = -1.5^\circ$

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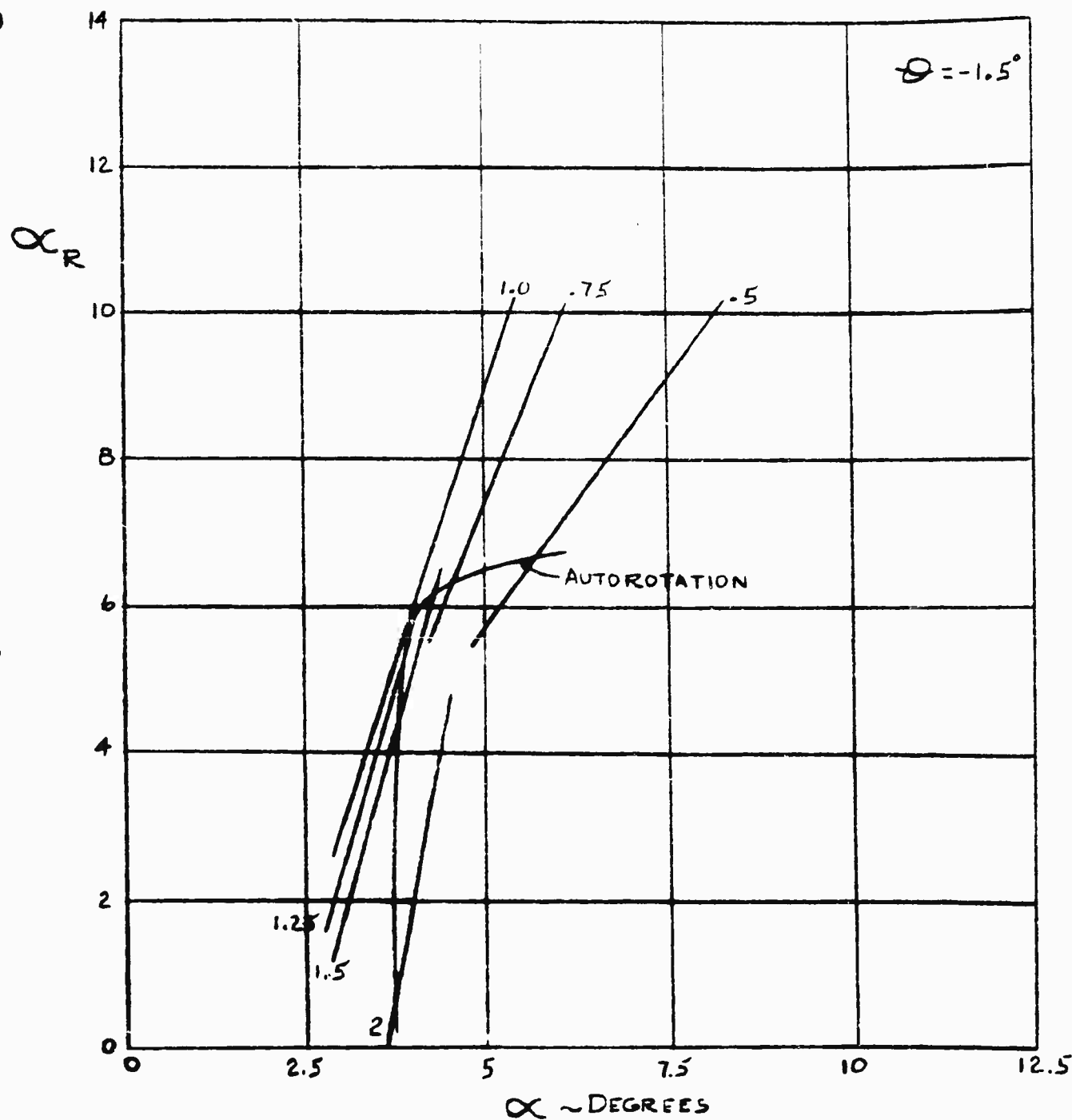


FIGURE 13

ROTOR PLANE POSITION α_R PLOTTED AGAINST α FOR ZERO TIP DRAG
AND BLADE PITCH $\theta = -1.5^\circ$

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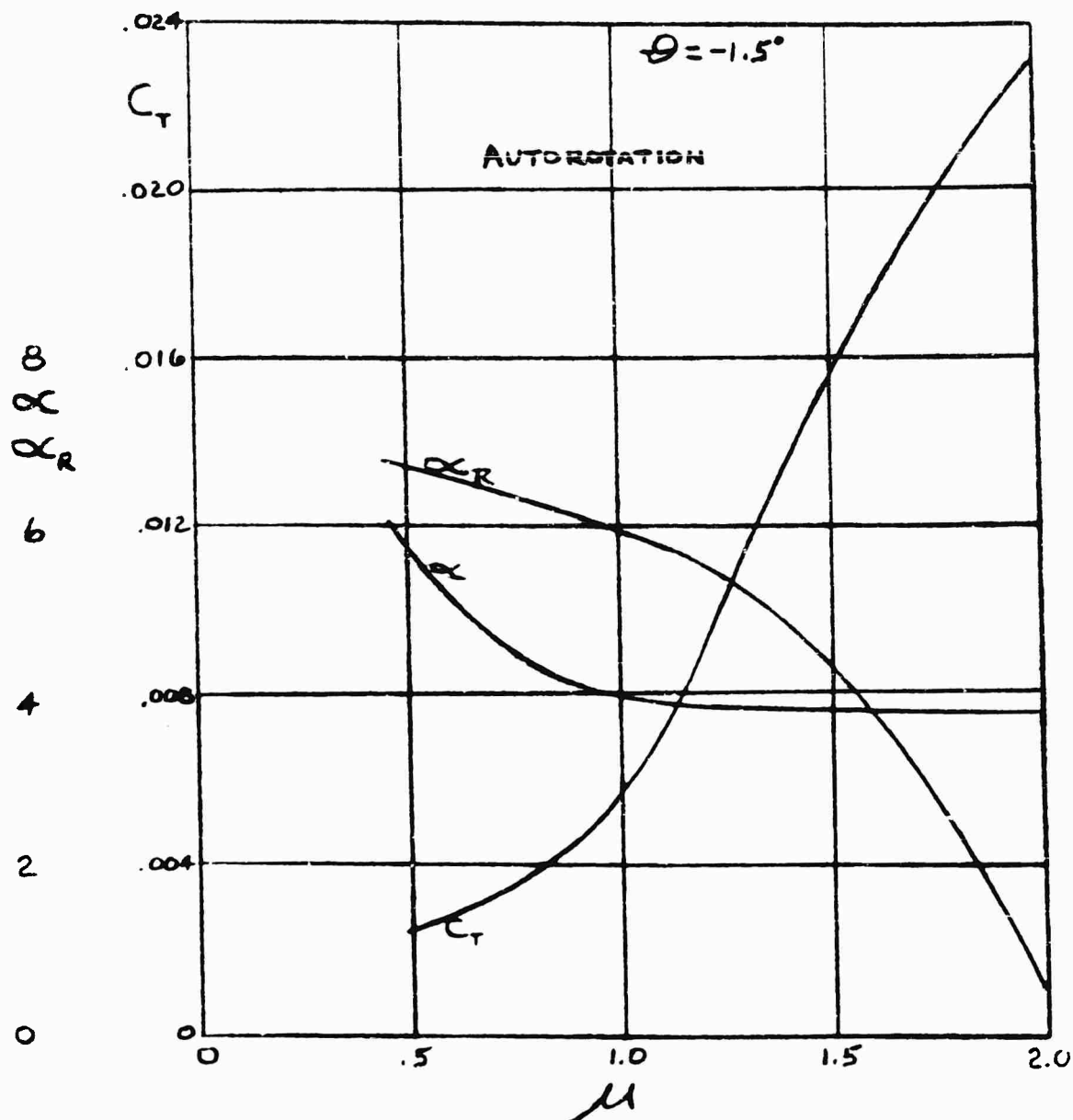


FIGURE 14

THRUST COEFFICIENT C_T , POSITION OF CONTROL PLANE α AND POSITION OF PLANE OF ROTATION α_R PLOTTED AGAINST ADVANCE RATIO μ FOR BLADE PITCH $\theta = -1.5^\circ$ IN AUTOROTATION

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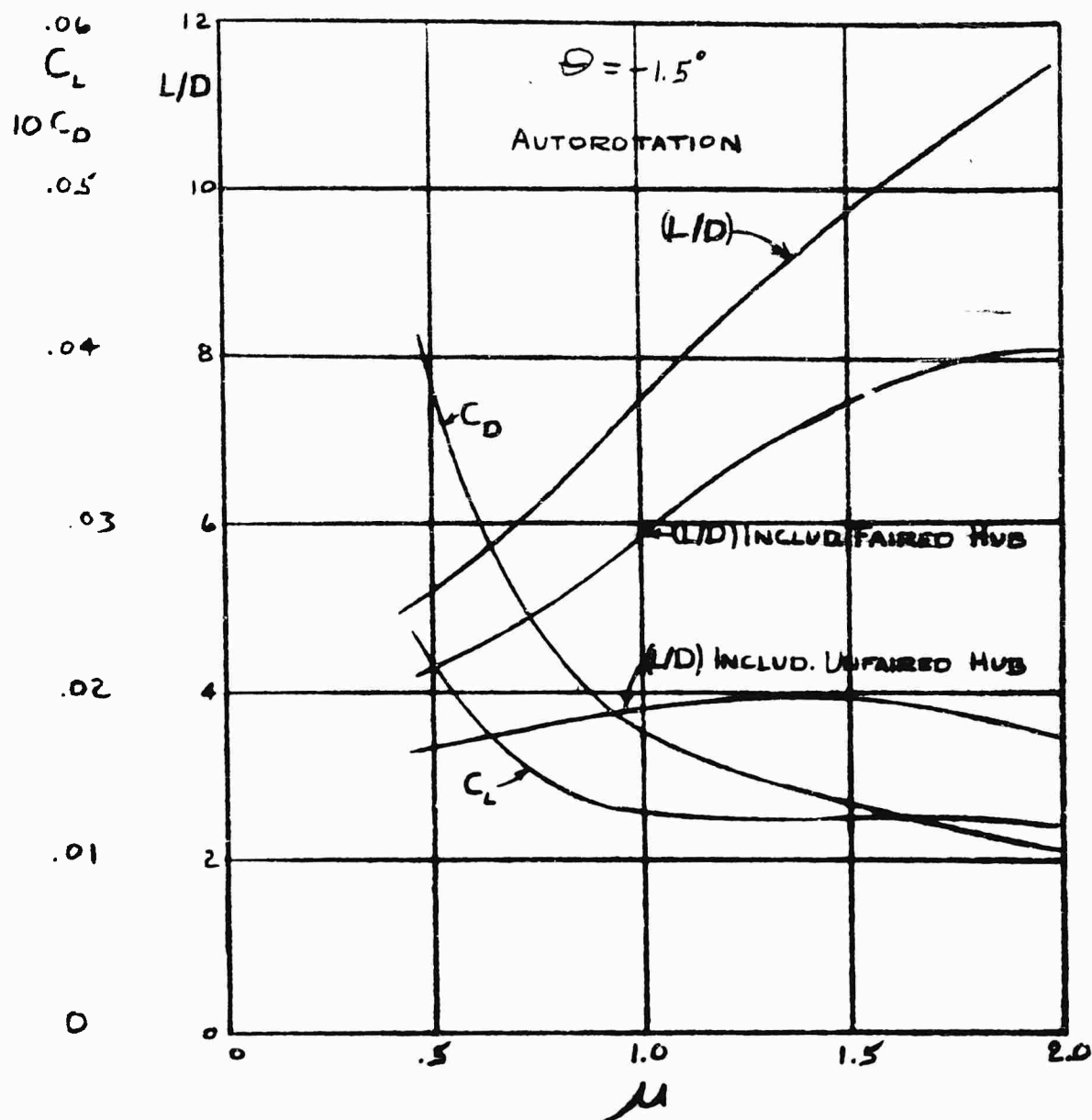


FIGURE 15

LIFT TO DRAG RATIO (L/D), LIFT COEFFICIENT C_L AND DRAG COEFFICIENT C_D PLOTTED AGAINST ADVANCE RATIO μ FOR BLADE PITCH $\theta = -1.5^\circ$ IN AUTOROTATION

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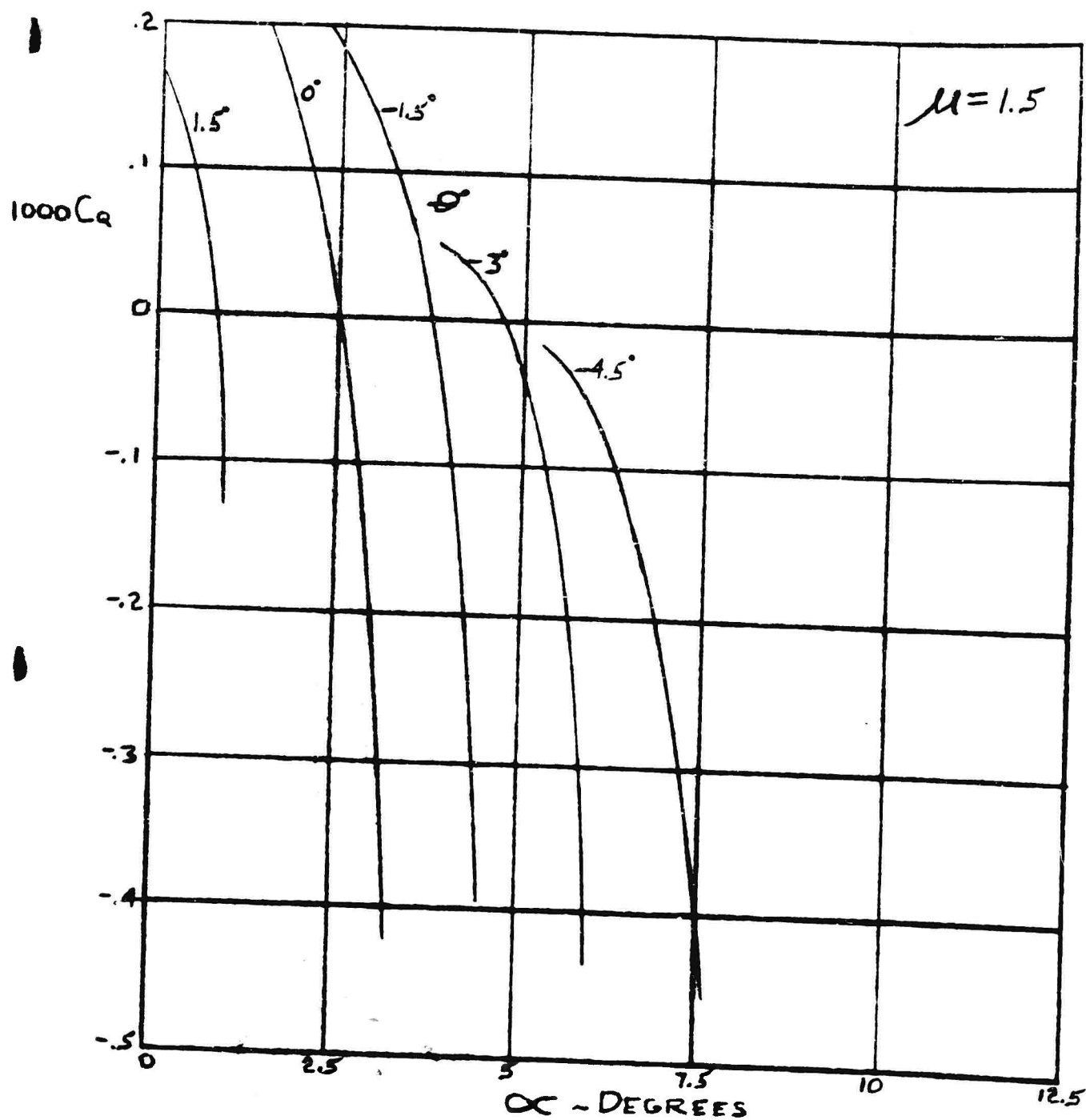
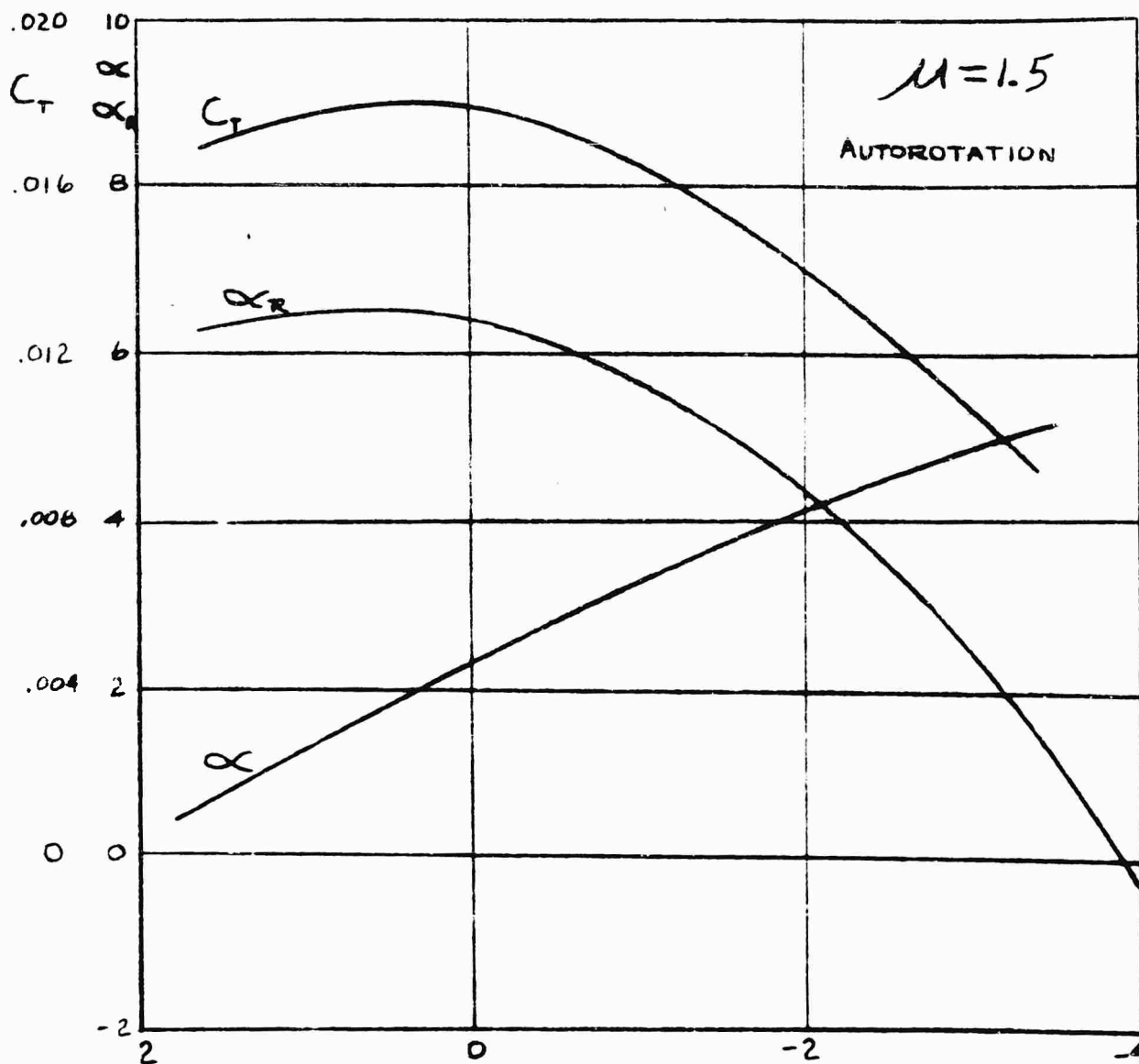


FIGURE 16

TORQUE COEFFICIENT C_q PLOTTED AGAINST α FOR ZERO
TIP DRAG AND ADVANCE RATIO $\mu = 1.5$

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θ ~ DEGREES
FIGURE 17

THRUST COEFFICIENT C_T , POSITION OF CONTROL PLANE α
AND POSITION OF PLANE OF ROTATION α_R PLOTTED AGAINST
BLADE PITCH θ FOR ADVANCE RATIO $\mu=1.5$ IN AUTOROTATION

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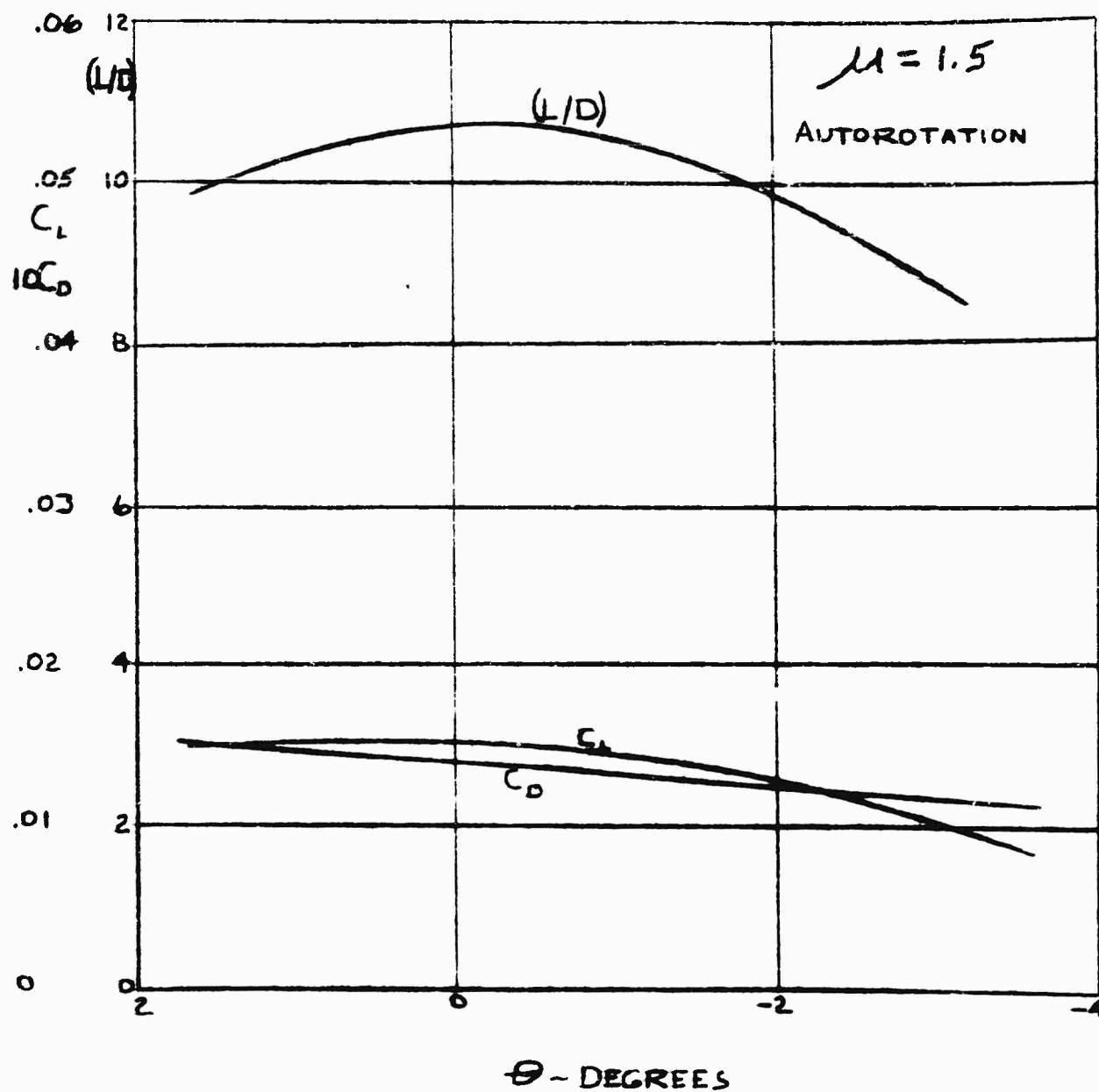


FIGURE 1B

LIFT TO DRAG RATIO (L/D) , LIFT COEFFICIENT C_L AND
DRAG COEFFICIENT C_D PLOTTED AGAINST BLADE PITCH
ANGLE θ FOR ADVANCE RATIO $\mu=1.5$ IN AUTOROTATION

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MODEL _____

7.0 TEST RESULTS IN GRAPHS

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SYMBOLS

a_1	Longitudinal Tilt of Tip Path Plane
E_0	Configuration Without Tip Balls
E_1	Configuration With Small Tip Balls
E_2	Configuration With Large Tip Balls
C_D	Drag Coefficient
C_L	Lift Coefficient
C_Q	Torque Coefficient
C_T	Thrust Coefficient
D	Drag in Pounds
L	Lift in Pounds
Q	Torque in Foot-Pounds
q	Dynamic Pressure, Lbs./Ft. ²
R	Rotor radius, Feet
(L/D)	Lift to Drag Ratio
α	Rotor Control Plane Angle
θ	Collective Pitch of Rotor Blades
μ	Advance Ratio

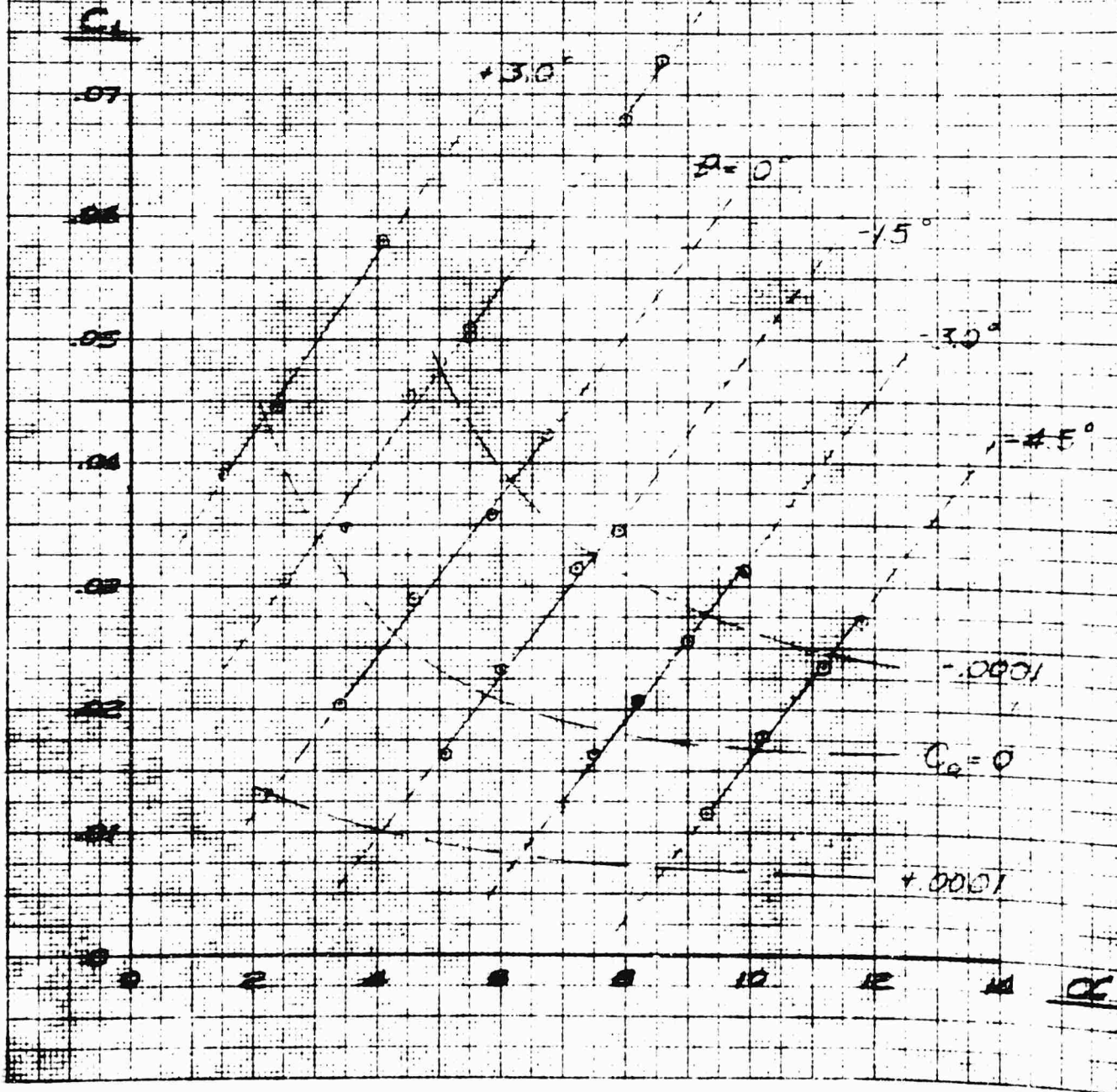
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CL VS OC

NAVAL OCT 49 TESTS
WITHOUT HUB DRAG

B
 $\mu = .5$

———— Measured
- - - - - Extrapolated
———— Constant C_d



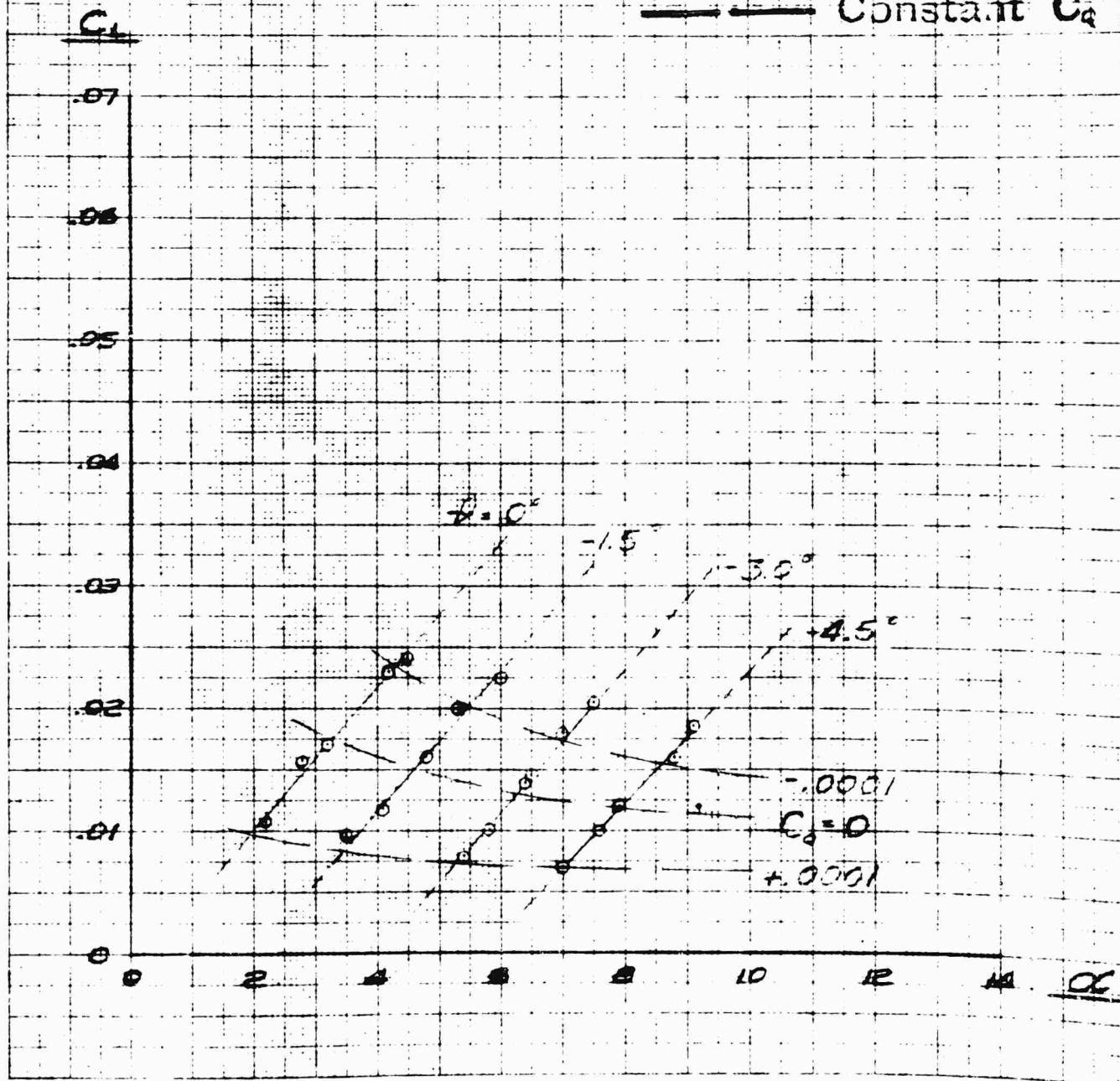
C_L VS OC

UNVAL OCT 49 TESTS
WITHOUT HUB DEAG

B.

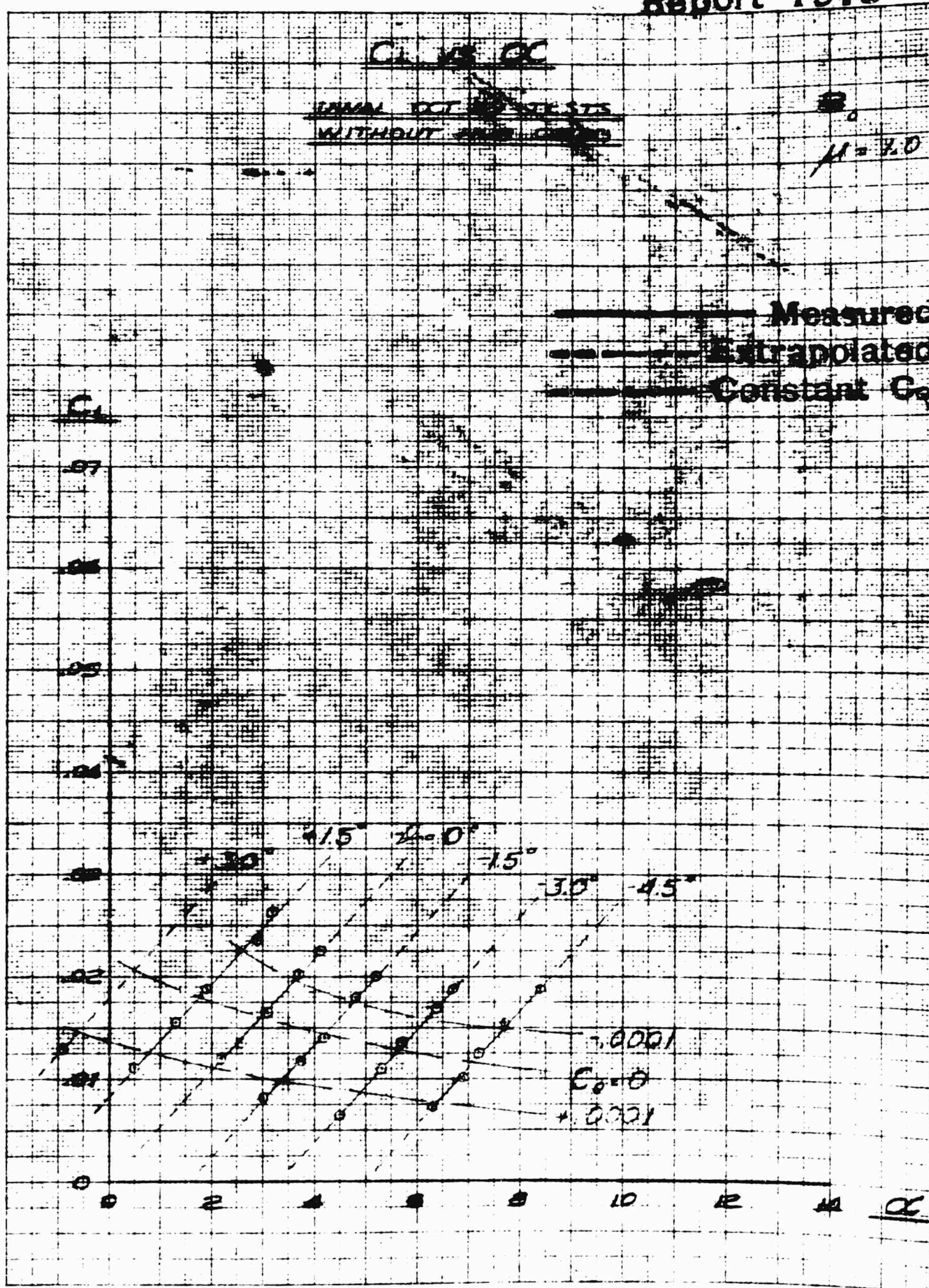
$\mu = 75$

———— Measured
----- Extrapolated
———— Constant C_d



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Report 1975

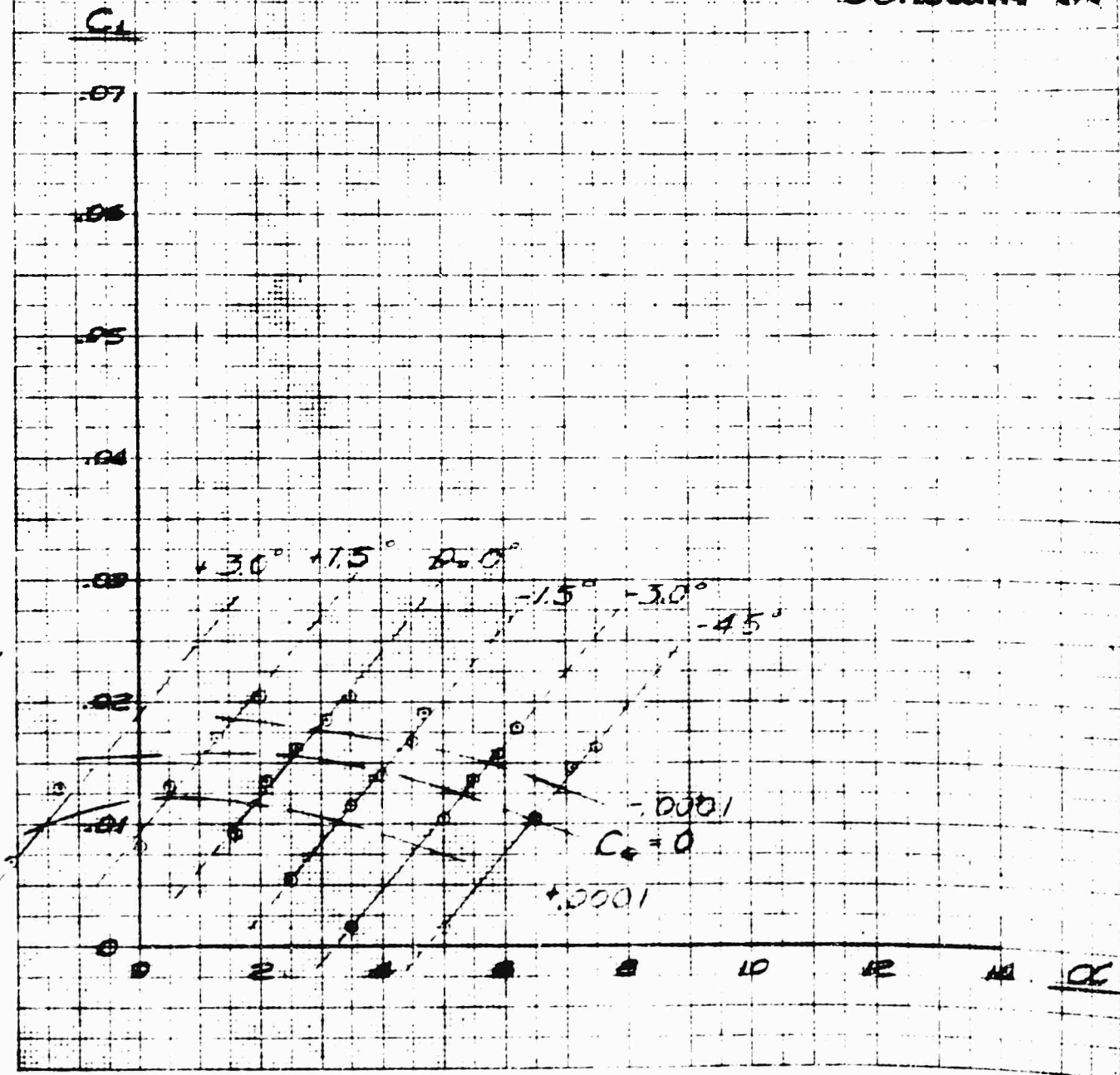


C_L VS α

UNVAL OCT 49 TESTS
WITHOUT HUB DRAG

B_0
 $\mu = 1.25$

————— Measured
- - - - - Extrapolated
————— Constant C_D



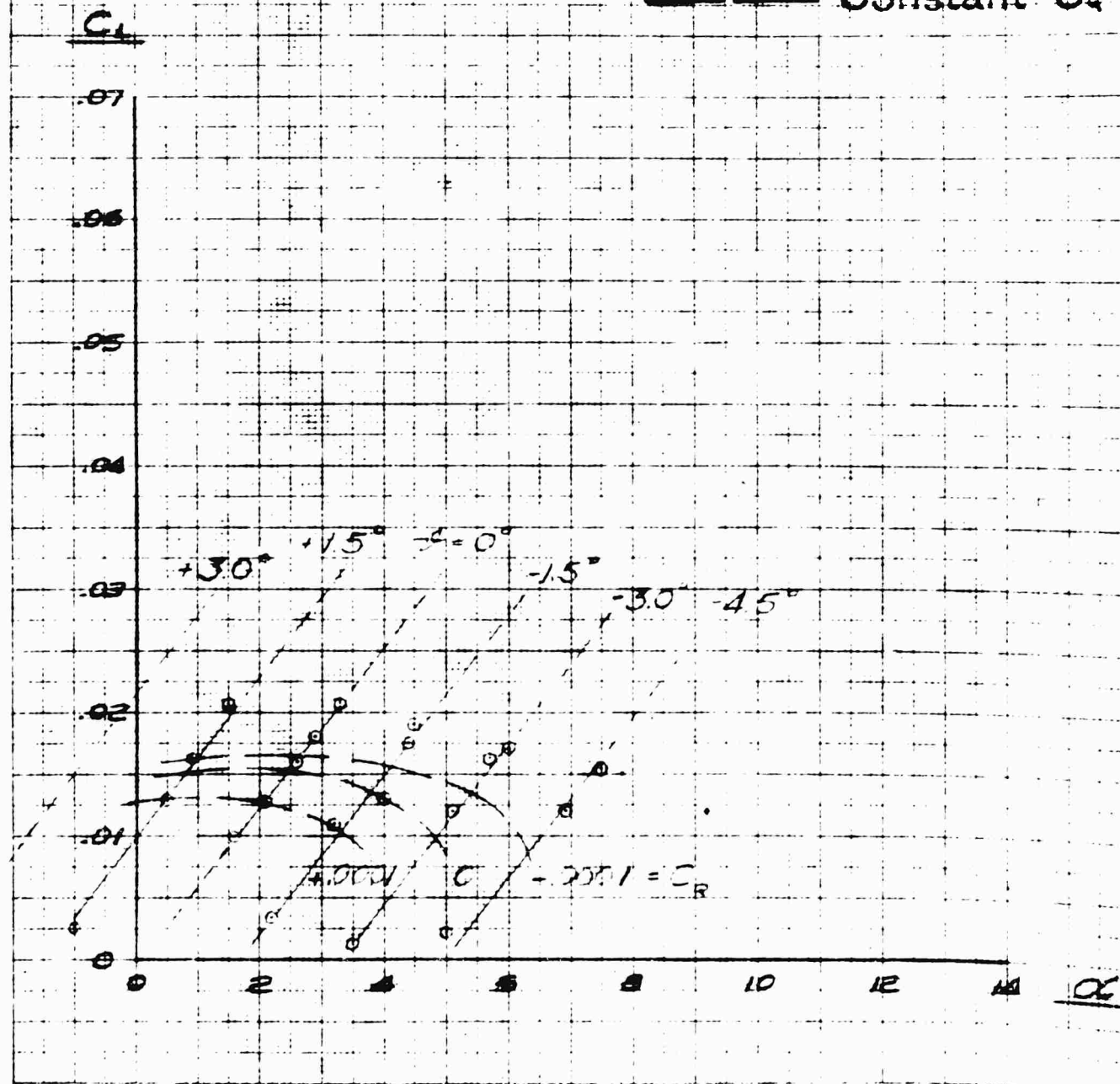
C_L VS α

UNVAL OCT 49 TESTS
WITHOUT HUB DRAG

B_c

$\mu = 15$

———— Measured
----- Extrapolated
———— Constant C_a

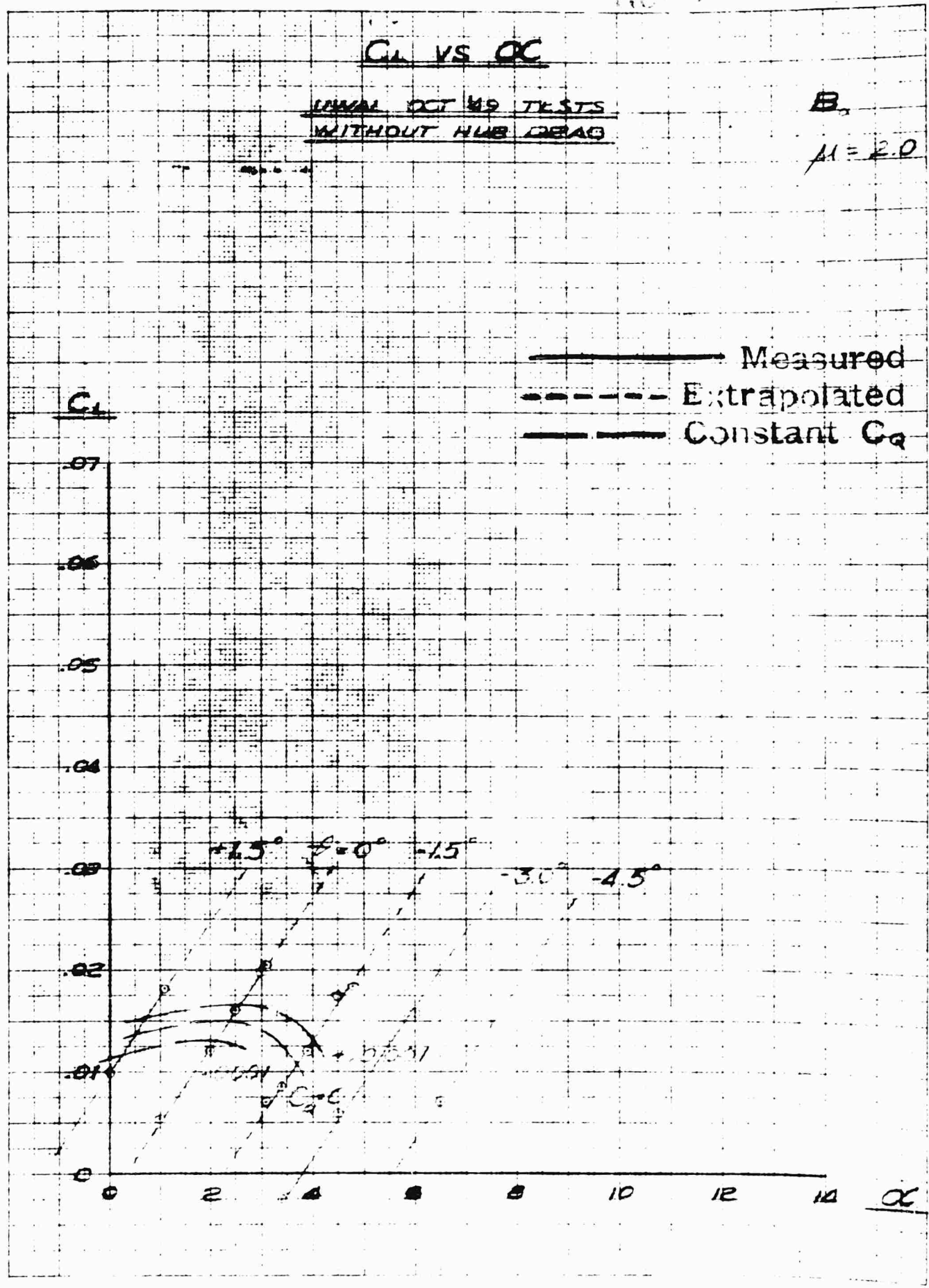


C_L VS α

UNWAL OCT 49 TESTS
WITHOUT HUB DEAD

B.

$M = 2.0$



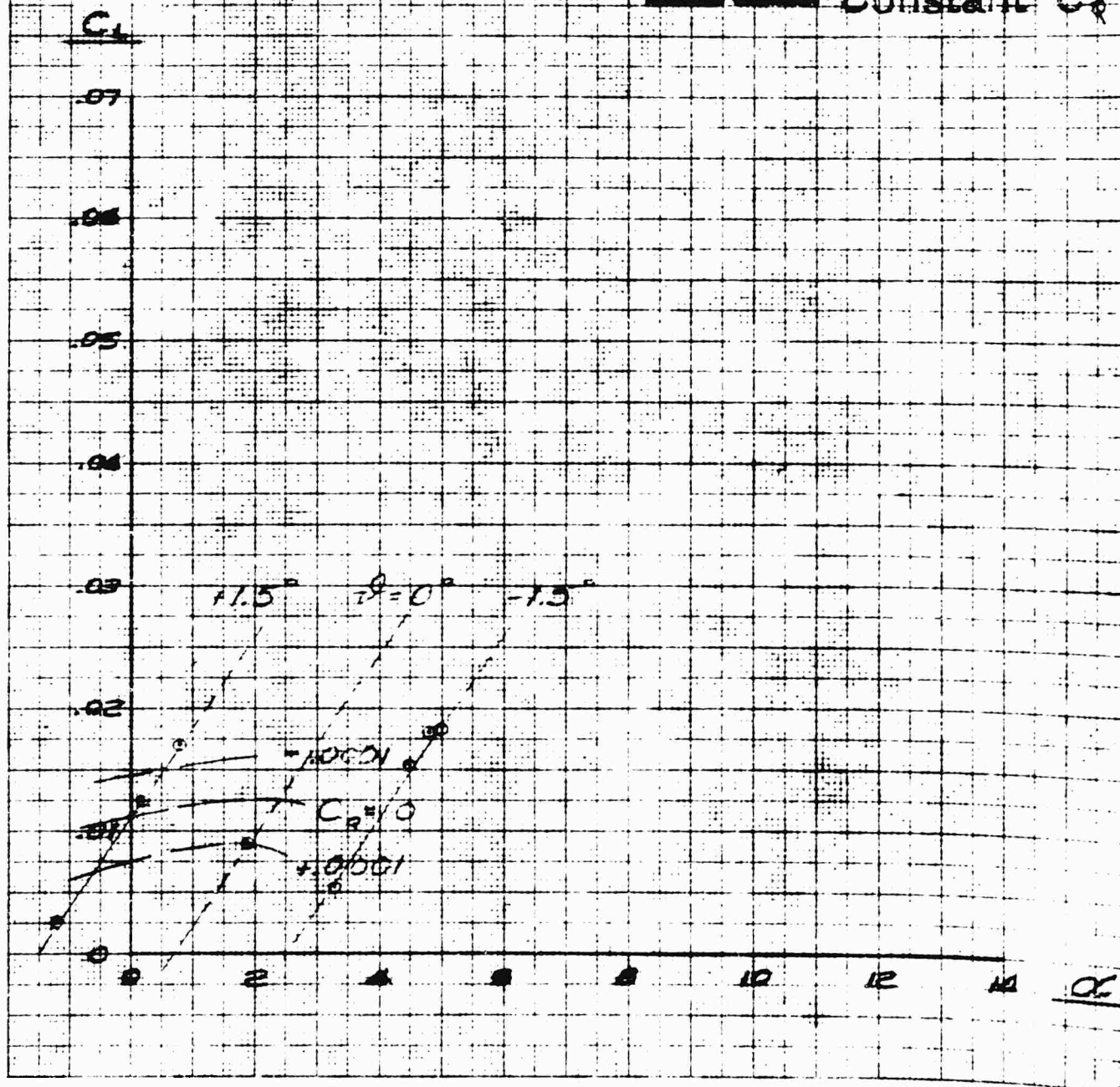
C_L VS OC

UNVAL. DOT HD TESTS
WITHOUT HIVE DEAD

B_0

$M = 2.5$

————— Measured
----- Extrapolated
————— Constant C_0



CT VS OC

$10^3 C_T$

UWAL OCT '49 TESTS
WITHOUT HUB DRAG

B.

$M = .5$

40

36

32

28

24

20

16

12

8

4

0

————— Measured
----- Extrapolated
————— Constant C_e

$\alpha = +3.0^\circ$

$+15^\circ$

0°

-15°

-30°

-45°

-60°

$C_e = 0$

$+0.001$

0 2 4 6 8 10 12 14 OC

C_T VS Q_C

10³ C_T

UNVAL OCT 49 TESTS
WITHOUT HUB DRAG

B₀

$\mu = .75$

40

36

32

28

24

20

16

12

8

4

0

————— Measured
----- Extrapolated
————— Constant C_q

$\alpha = 0^\circ$ -1.5° -3.0° -4.5°

-0.021

$C_{q} = 0$

$+0.021$

0

2

4

6

8

10

12

14

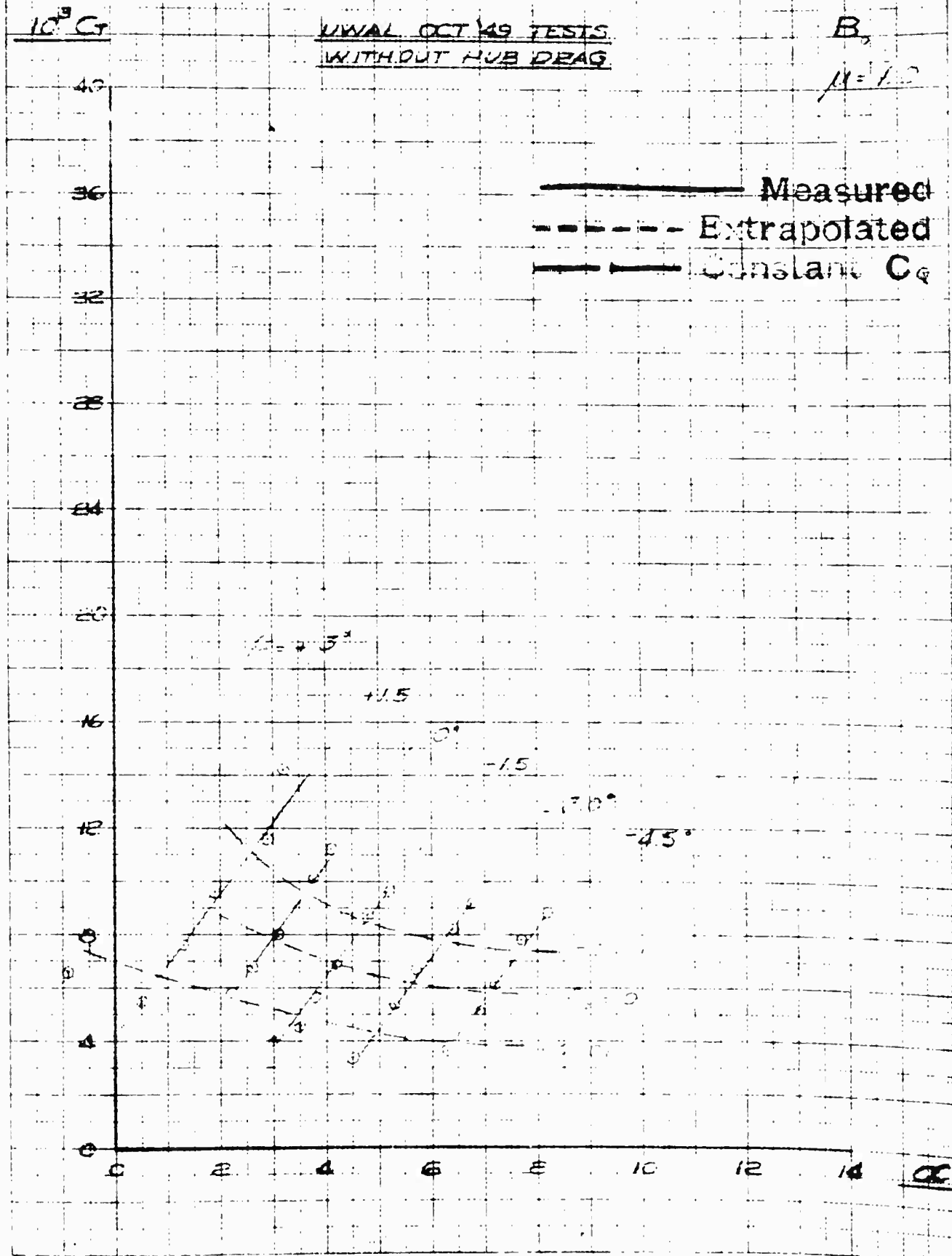
Q_C

CT VS OC

UWAL OCT 49 TESTS
WITHOUT HUB DRAG

B_1

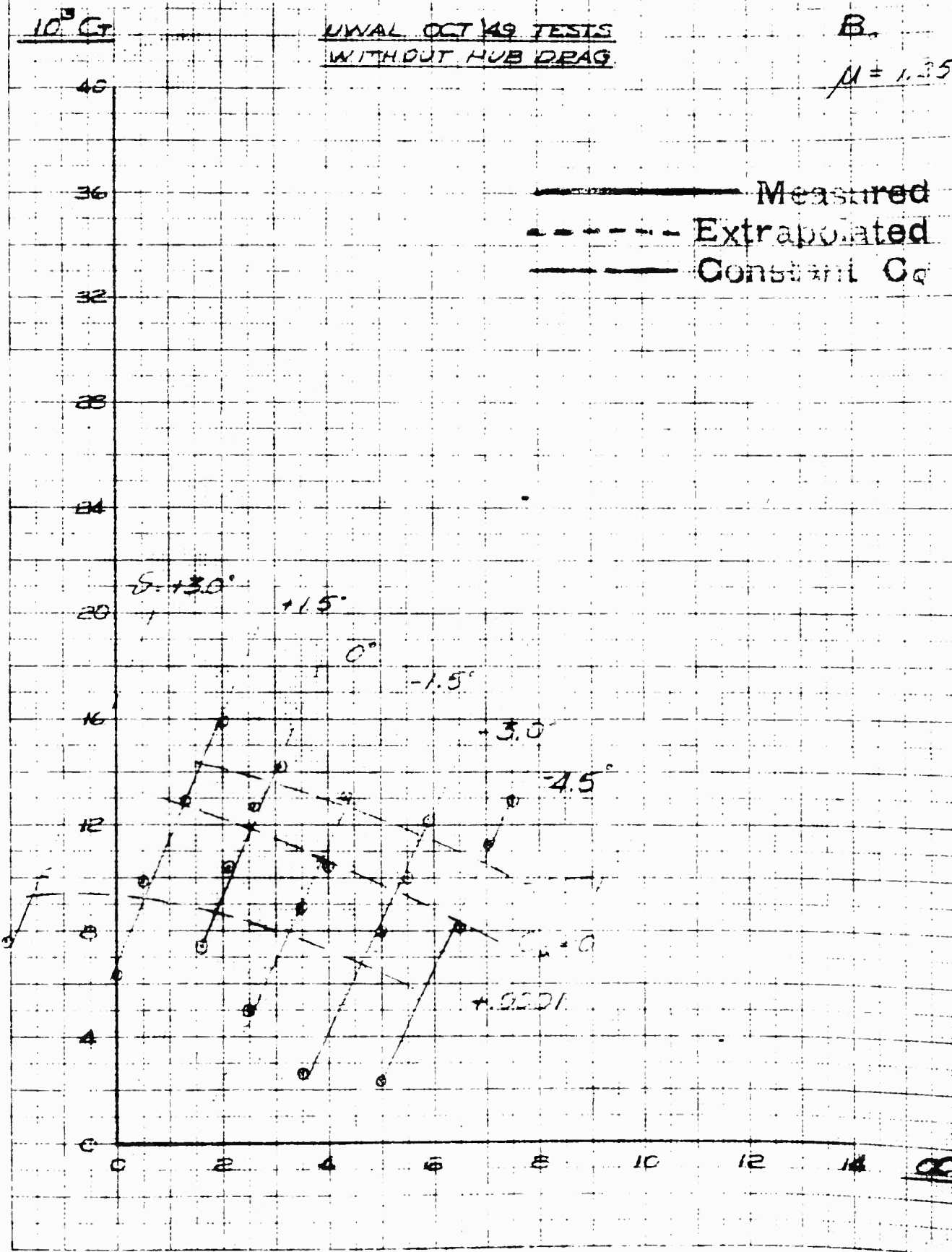
$\mu = 1.2$



CT VS OCUNVAL OCT 49 TESTS
WITHOUT HUB DRAG

B.

$$\mu = 1.35$$



CT VS OC

UWAL OCT 49 TESTS
WITHOUT HUB DRAG

B

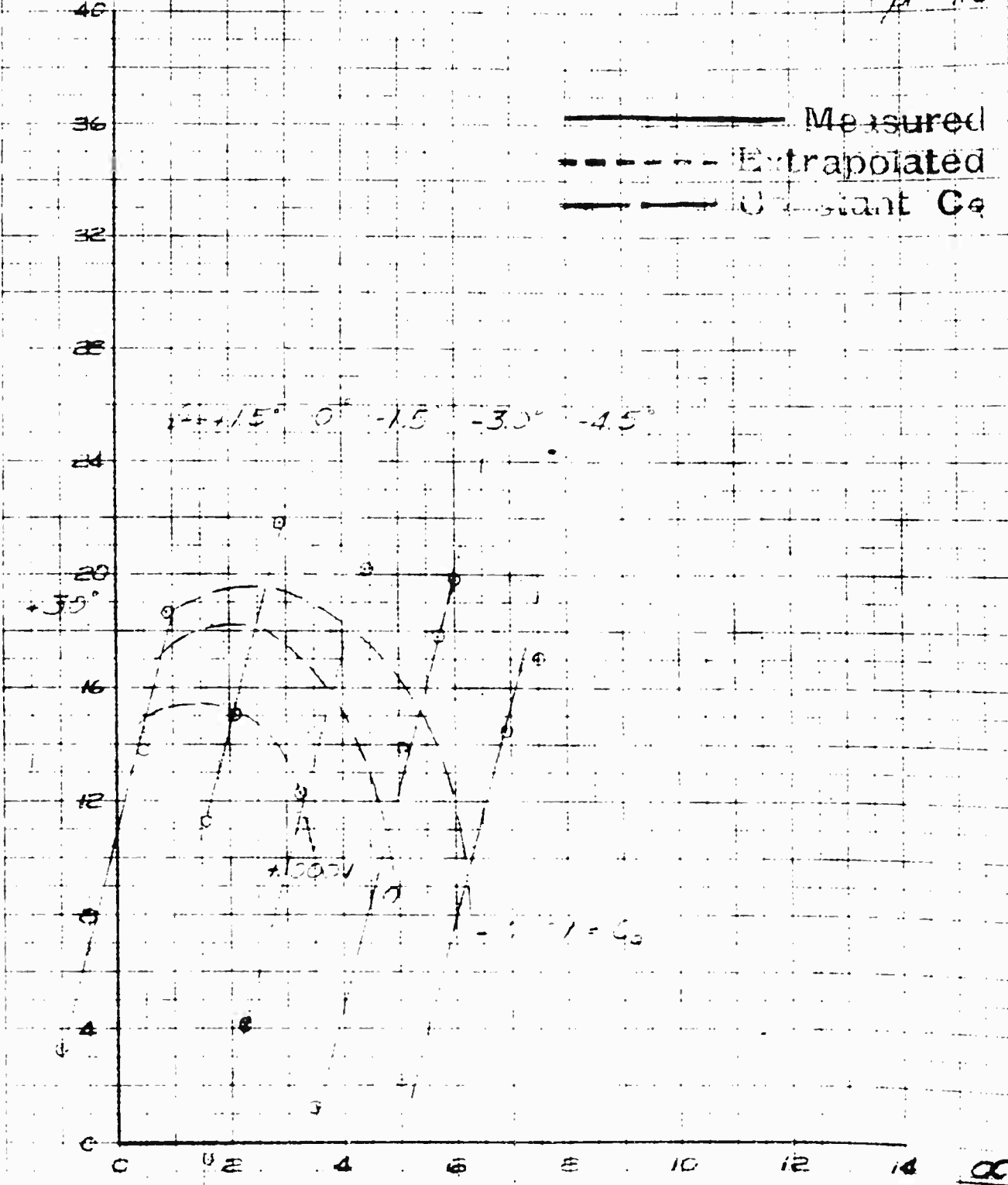
$\mu = 1.5$

$10^3 C_T$

————— Measured
- - - - - Extrapolated
————— Constant C_0

REYNOLDS & COOK CO

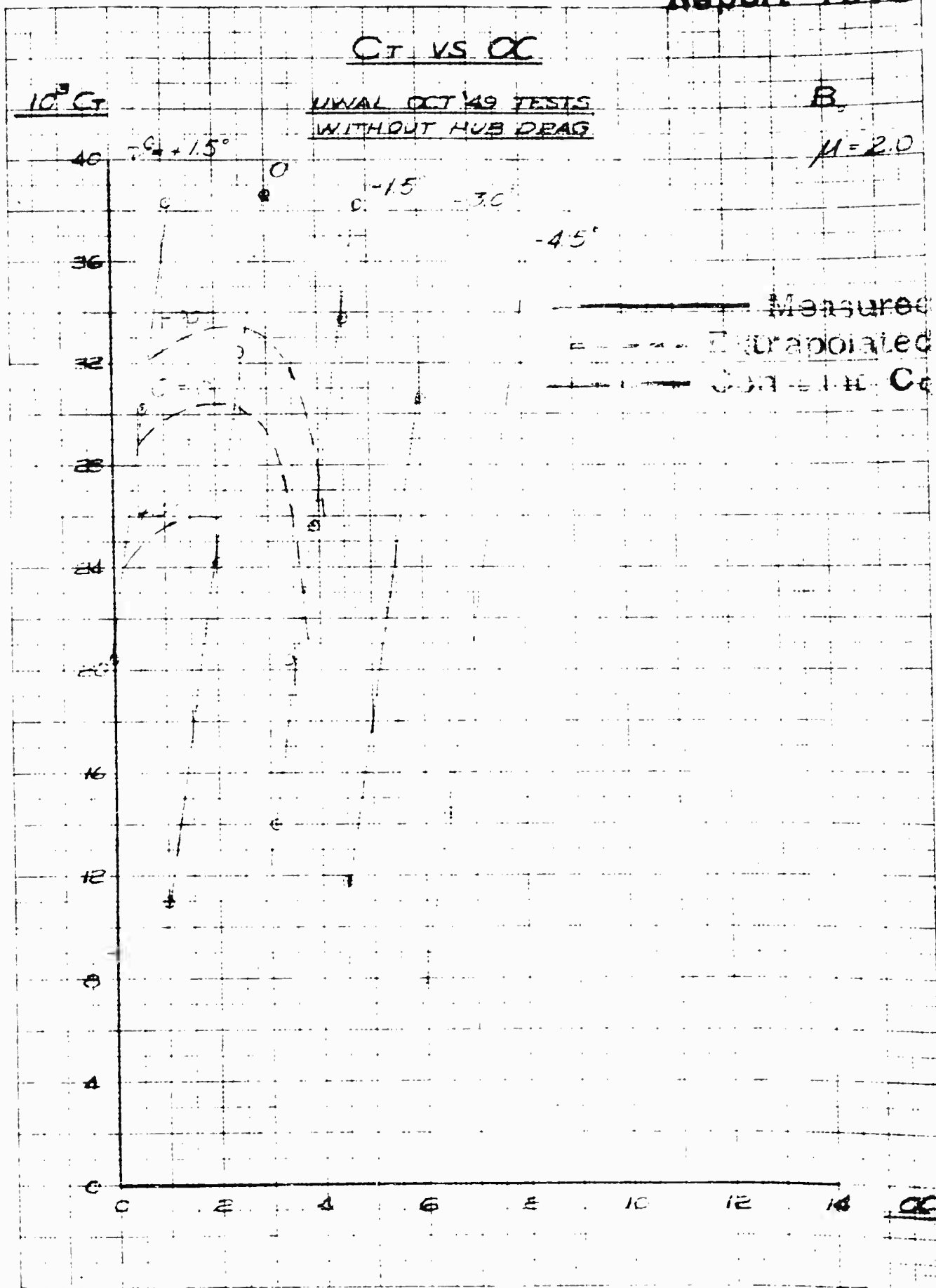
No. 3 511 Millimeter, 5 mm long, 1.5 mm line, head



C_T VS Q_C

10³ G

UNVAL OCT '49 TESTS
WITHOUT HUB DRAG

$$\mu = 2.0$$


C_T VS α

 $10^3 C_T$

UNVAL OCT '49 TESTS
WITHOUT HUB DRAG

B.

M = 4.5

40

 $\beta = 0^\circ$

-15

36

2007

32

Measure

Extrapolated

Constant C_a

28

24

20

16

12

8

4

0

0

2

4

6

8

10

12

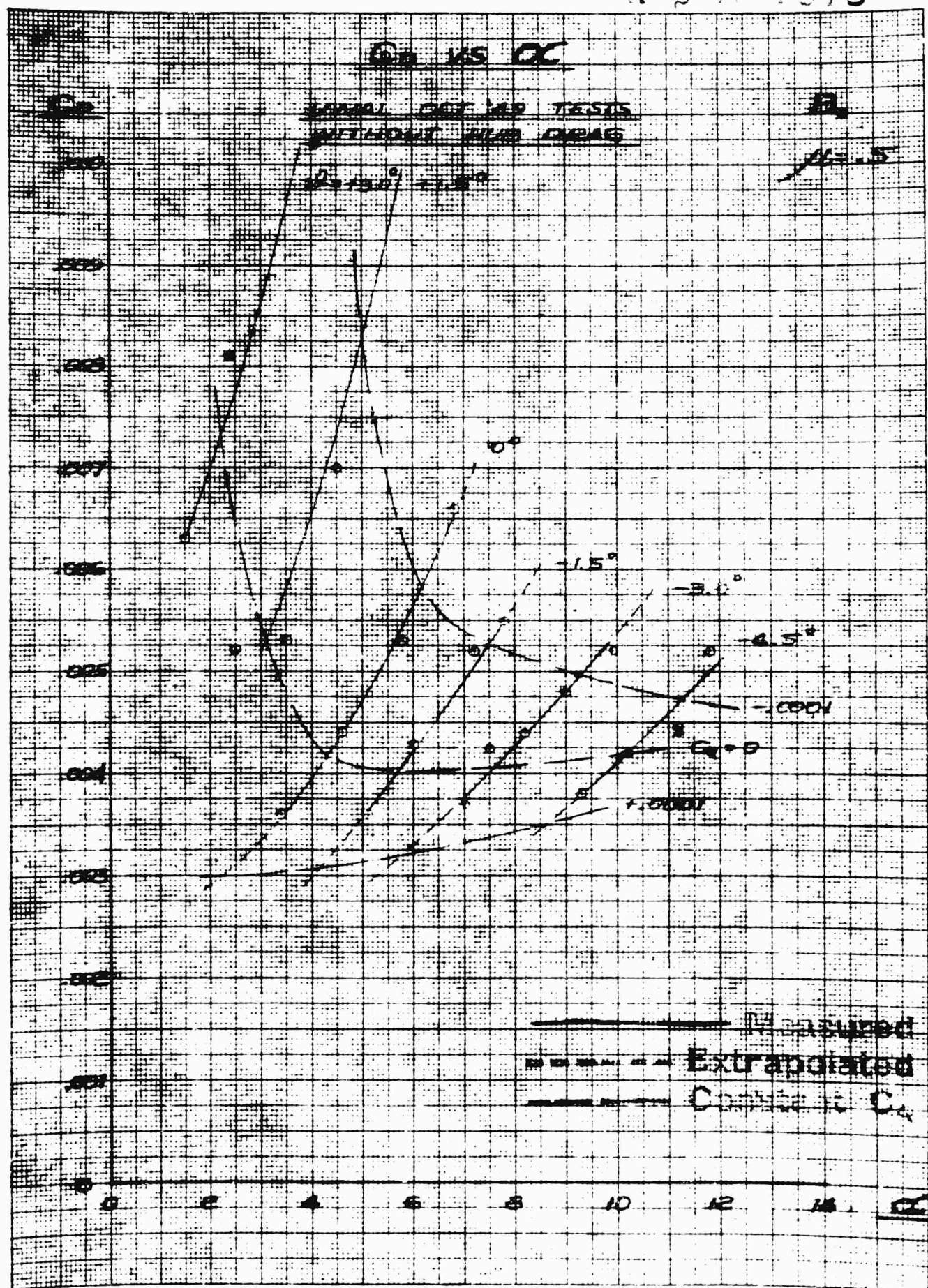
14

 α

PCL

1307

R 2 1978

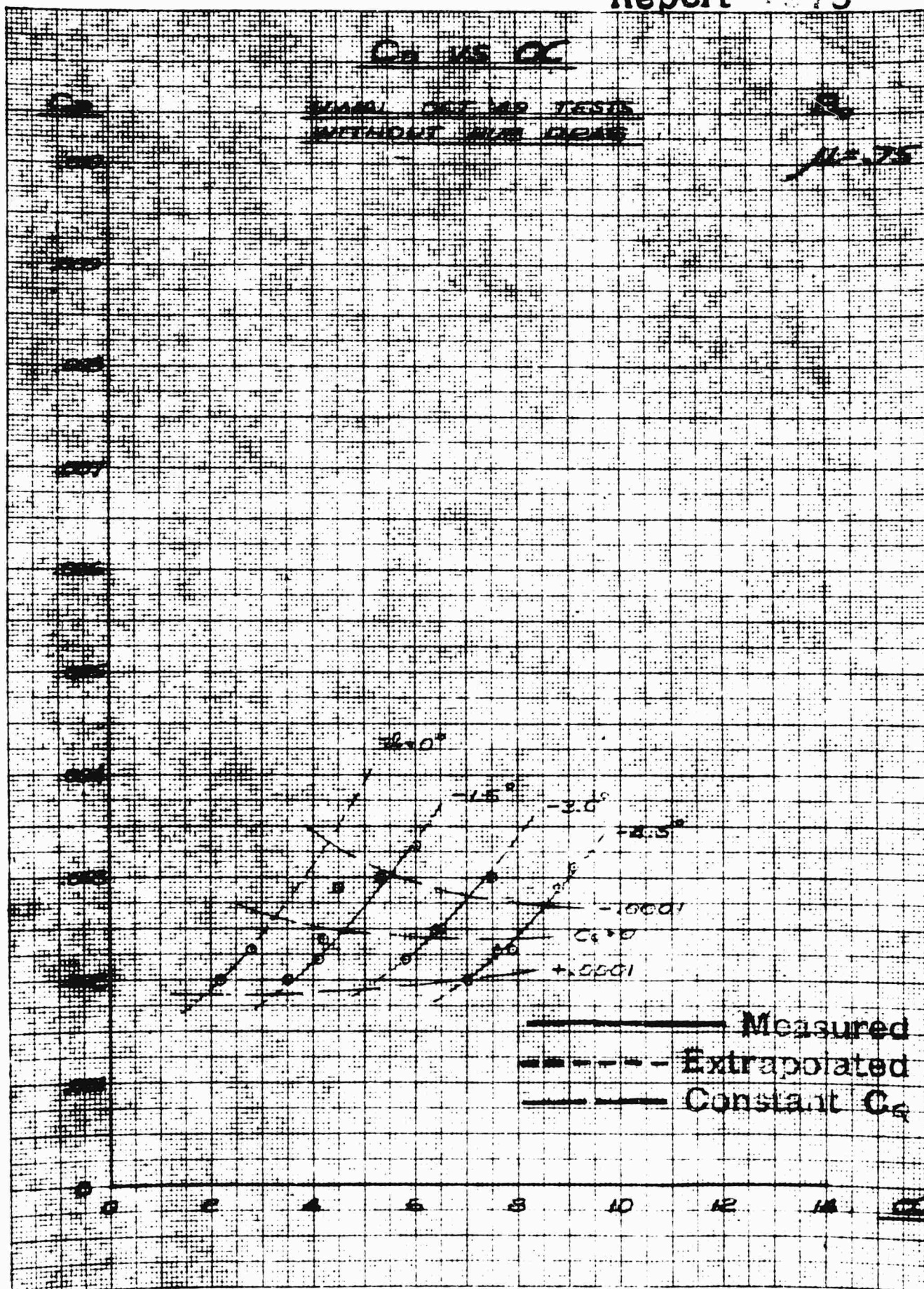


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KEUFFEL & ESSER CO.

No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy

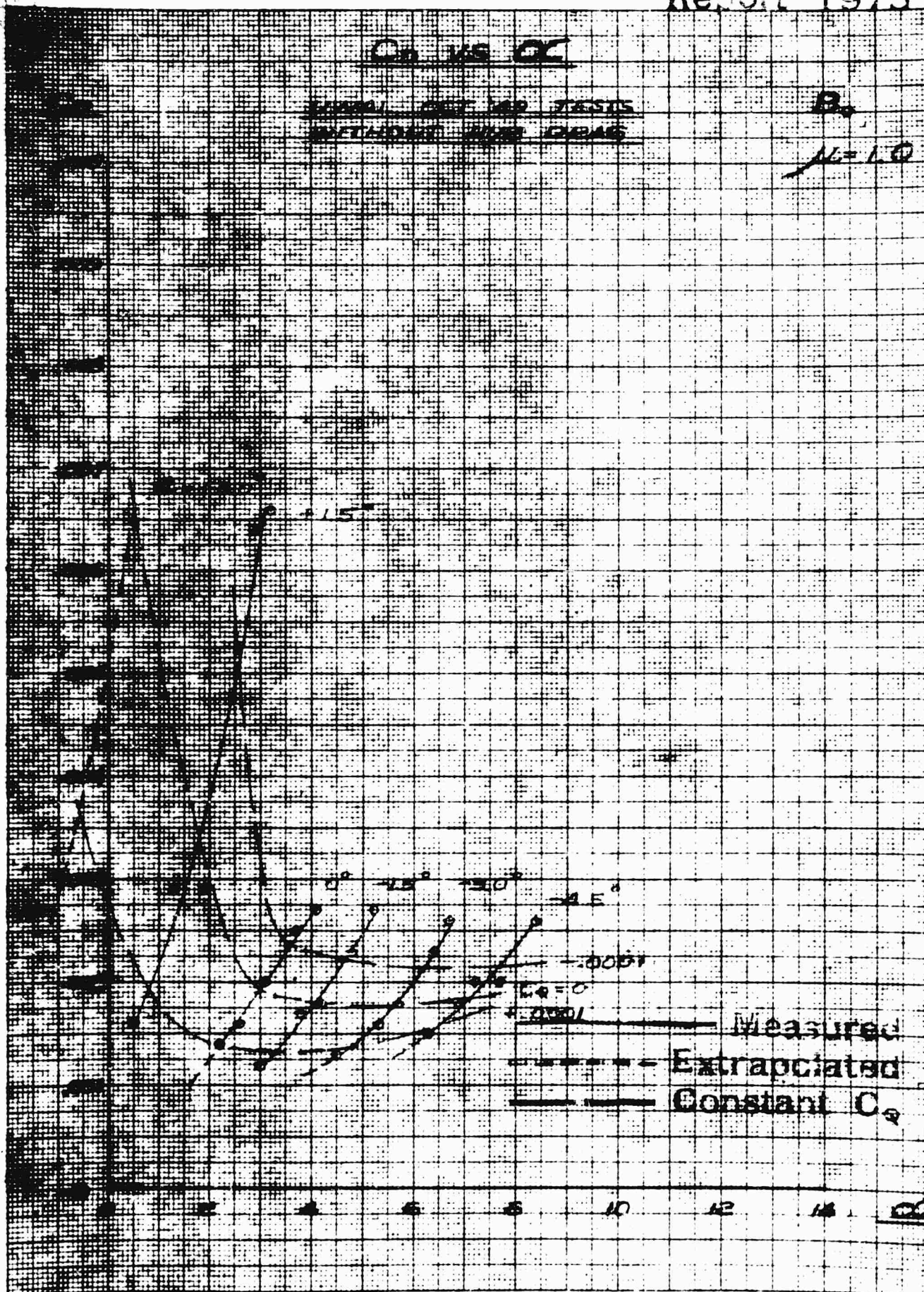


C_D VS OC

WIND TUNNEL TESTS
WITHOUT AND WITH DRAG

B_0

$AL = 1.0$

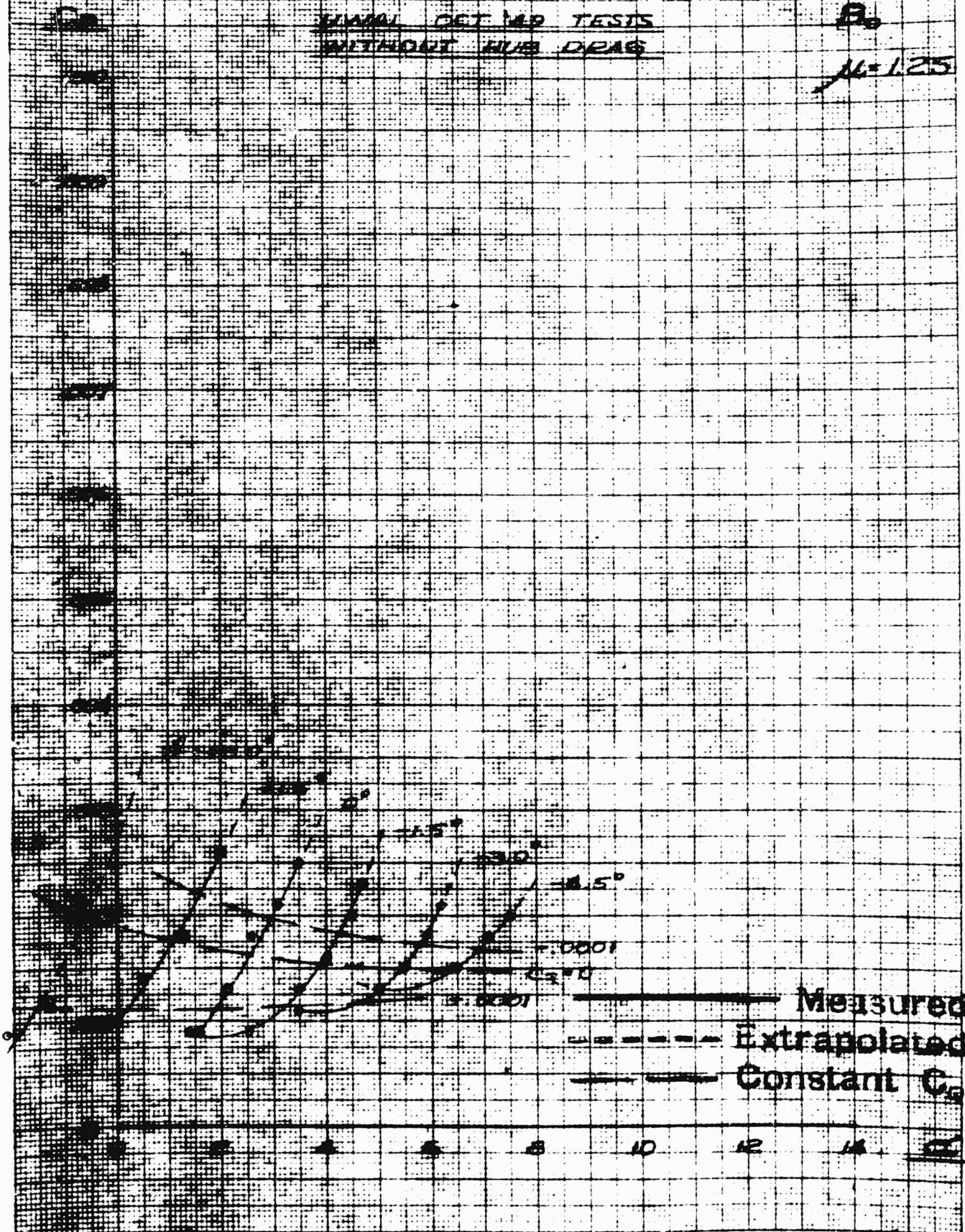


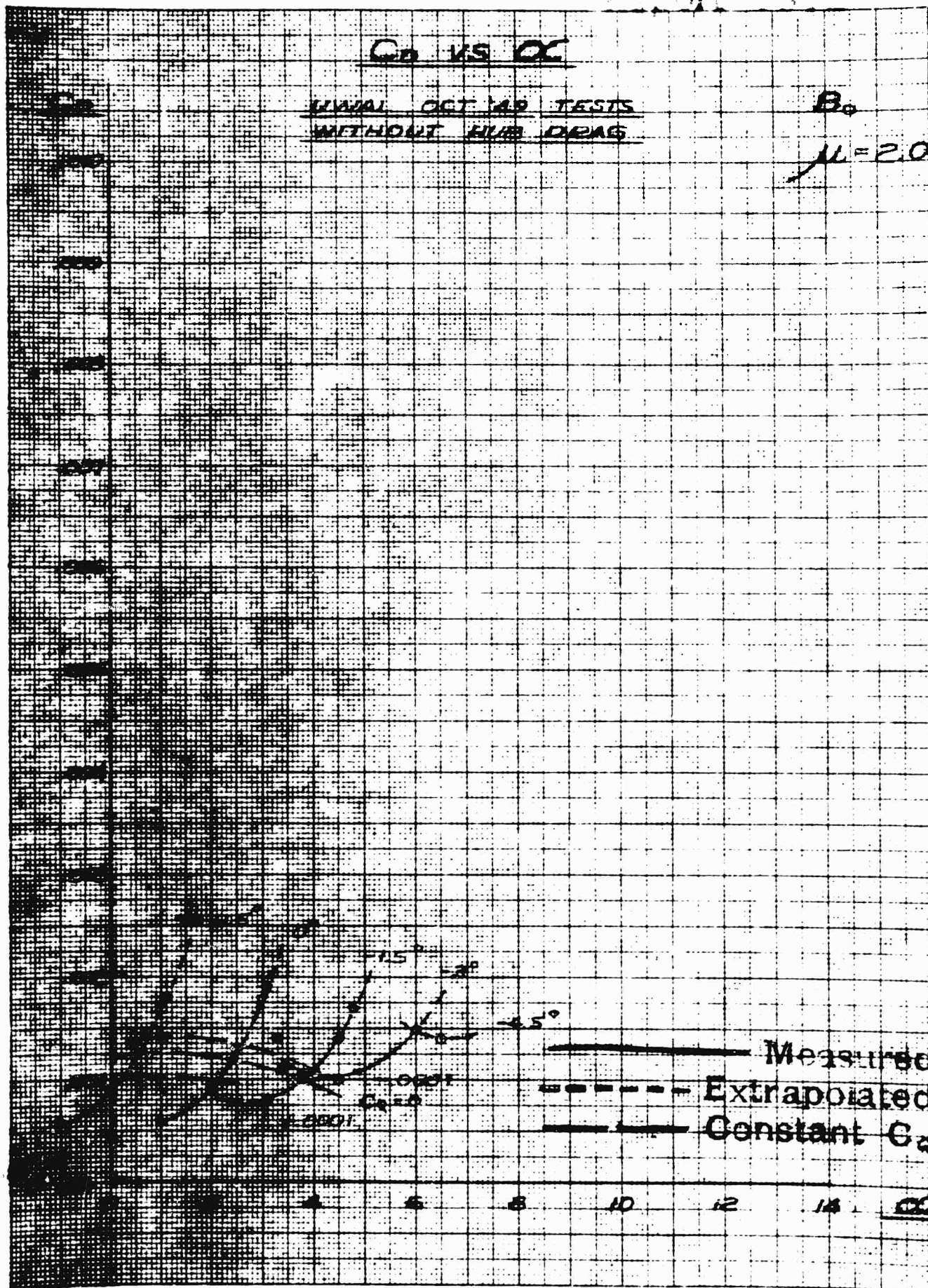
C_D VS OC

WIND TUNNEL TESTS
WITHOUT HUB DRAG

B_0

$M=1.25$



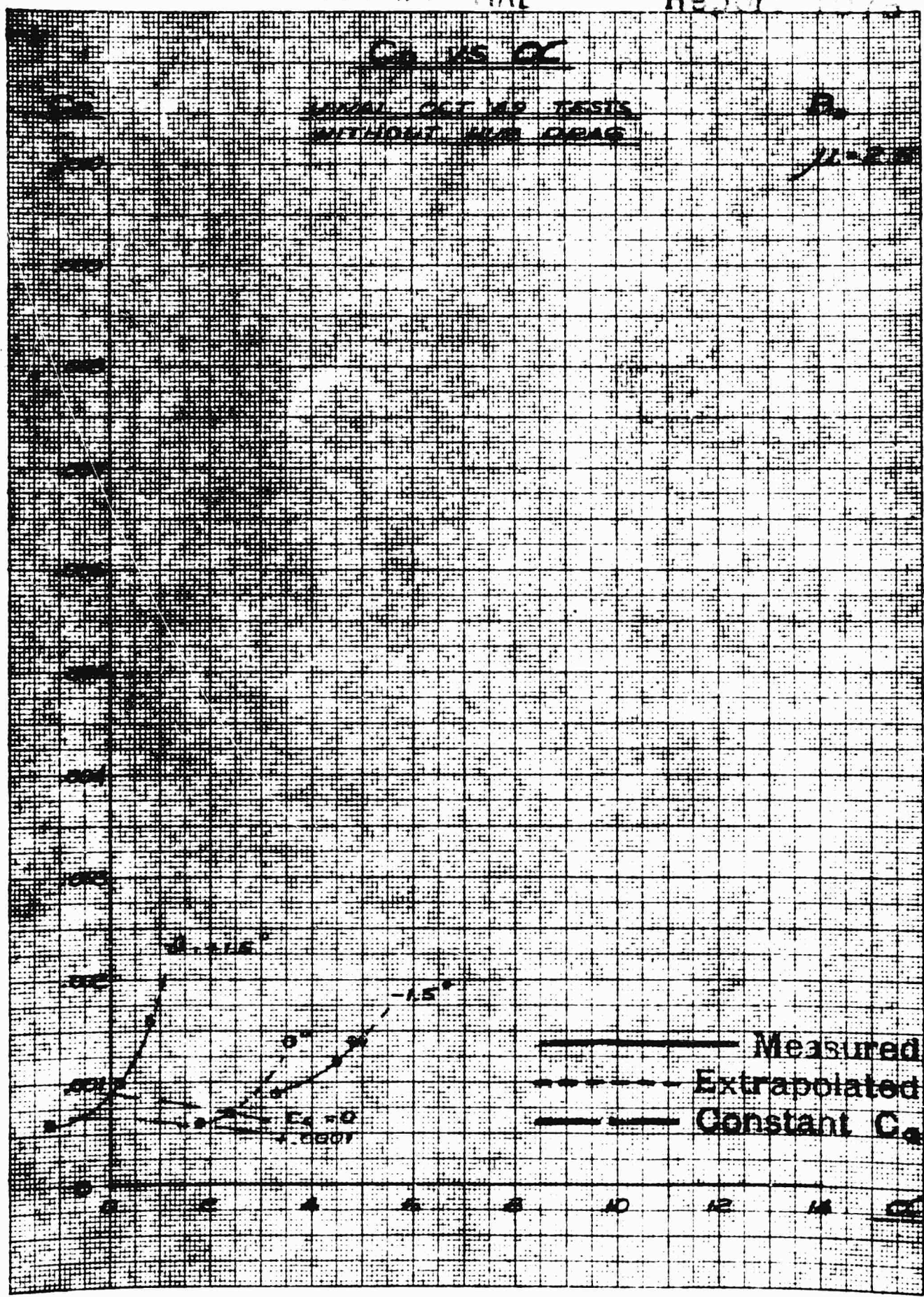
C_D VS OC WIND TUNNEL TESTS
WITHOUT HUB DRAG B_0 $\mu = 2.0$ 

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KEUPPEL & ESSER CO.

No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.
MANUFACTURED IN U.S.A.



SYNOPSIS

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Report #950

L/D VS OC

UNAL-OCTAS TESTS
WITHOUT HUB DRAG

B_0

$M = .5$

L/D

16

14

12

10

8

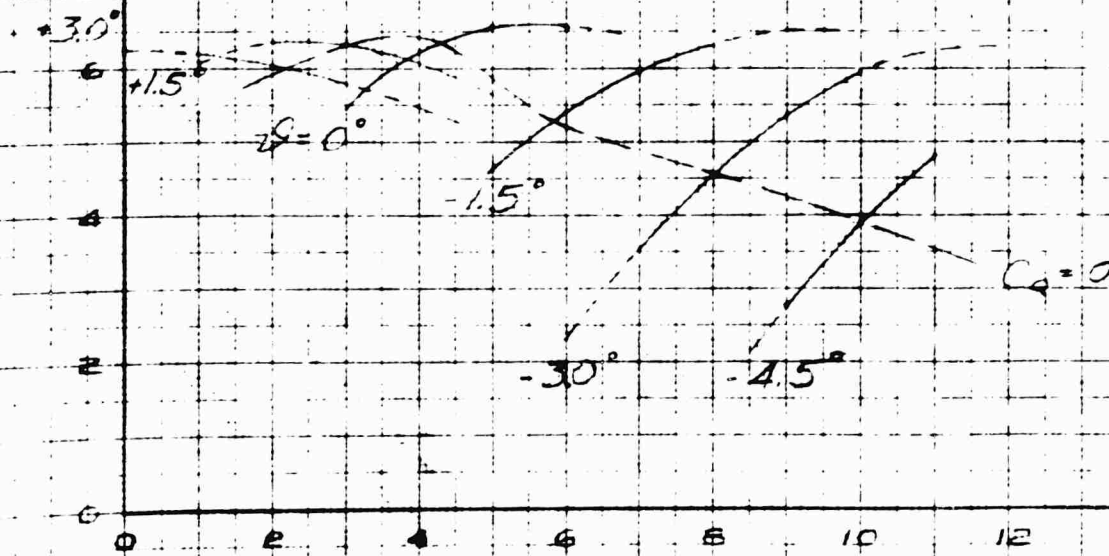
6

4

2

0

— Measured
- - - Extrapolated
— Constant C_d



CONCLUSION

PC-1213-4

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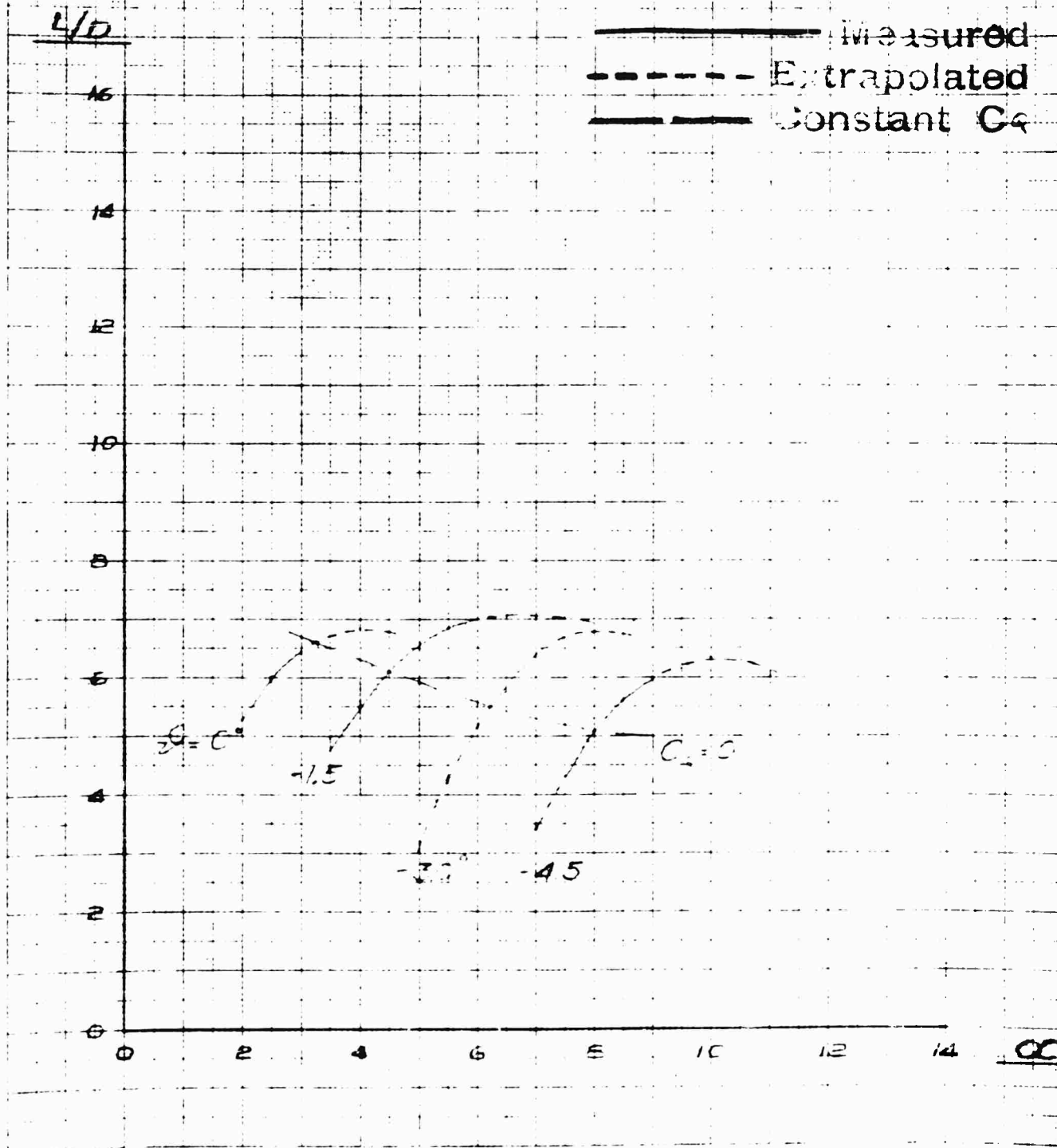
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L/D vs OC

UNVAL OCT 49 TESTS
WITHOUT HUB DRAG

B₀

$\mu = .75$

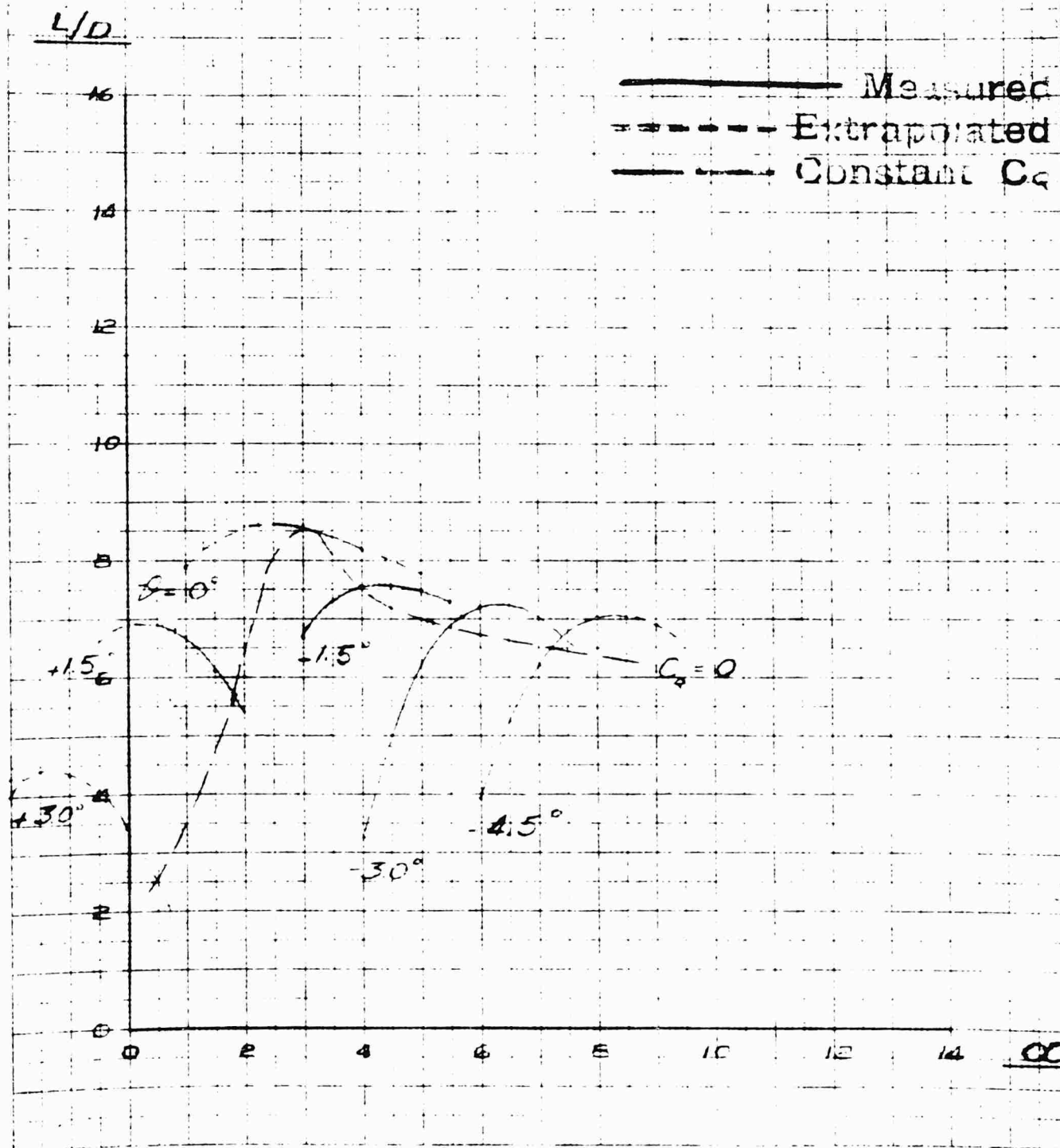


KIEHL & ESSER CO

20 2-9 14 20 2-9 14 20 2-9 14 20 2-9 14

UNVAL OCT 19 TESTS
WITHOUT HUB DRAG

B

$$\mu = 1.5$$


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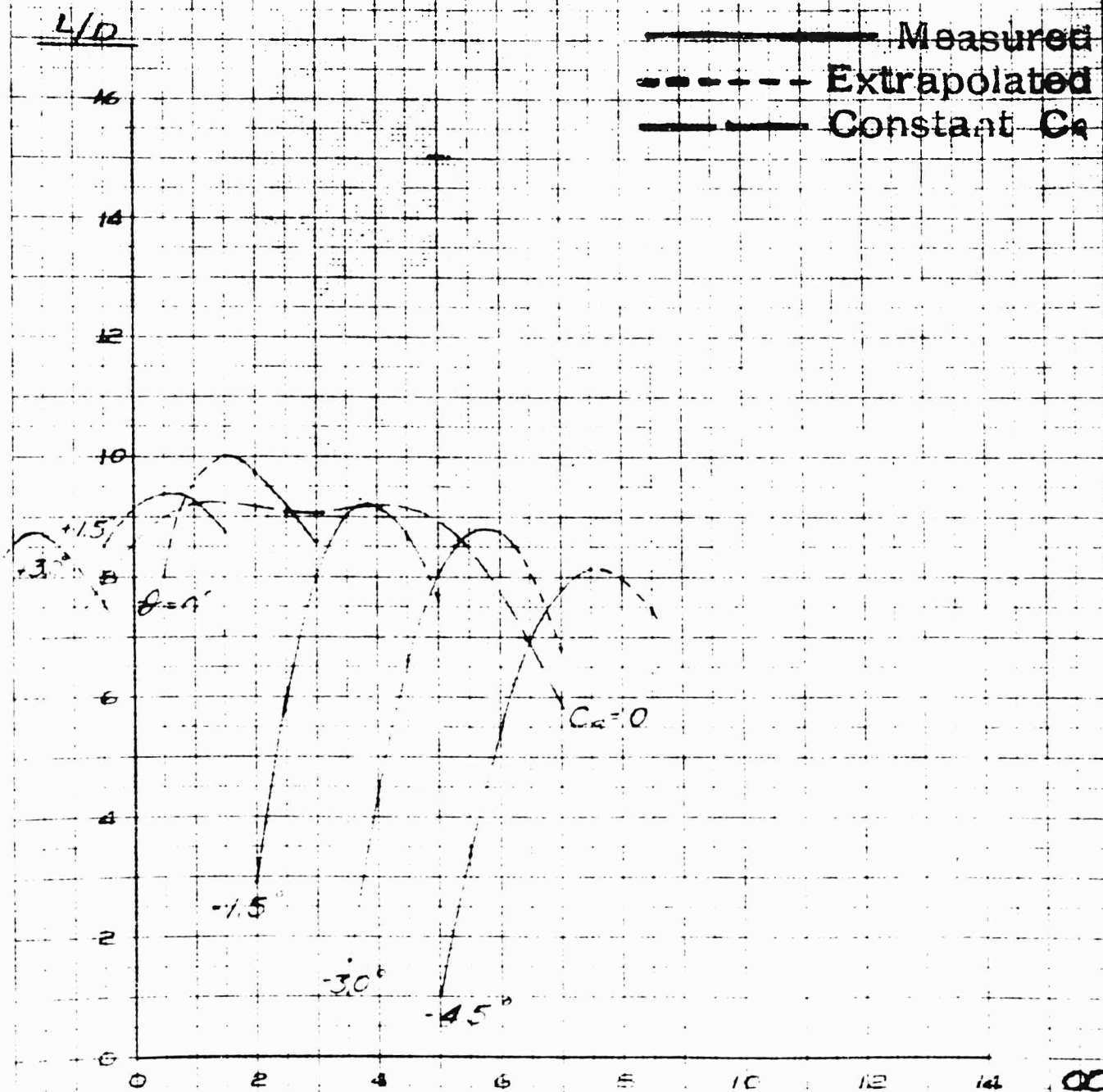
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L/D vs OC

UNVAL OCTAS TESTS
WITHOUT HUB DRAG

B_0

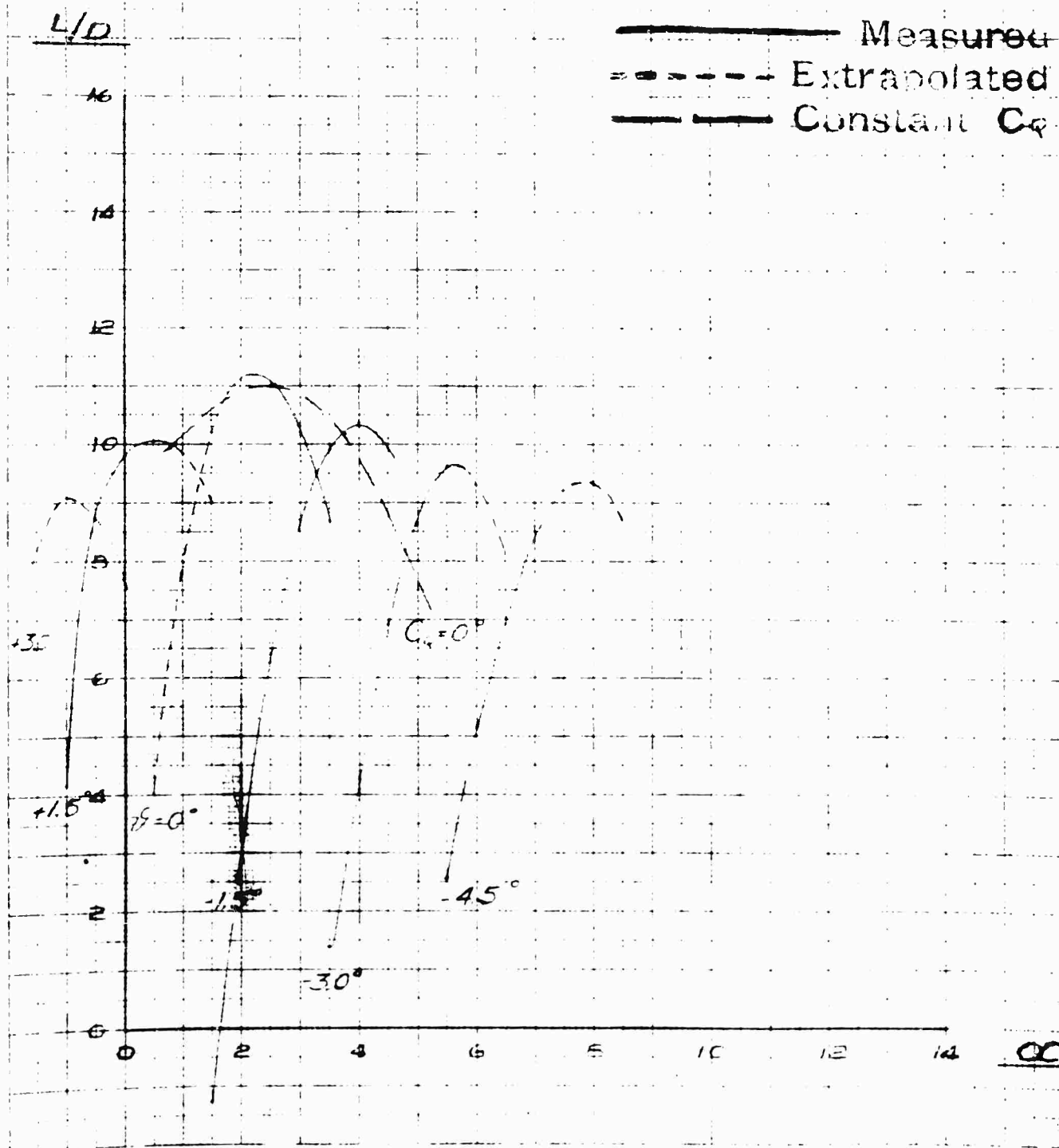
$M = 1.25$



MITCHELL & ENSER CO.

Fig. 1.1.1.1 - Unval Octas Tests Without Hub Drag

UNAL OCT 49 TESTS
WITHOUT HUB DRAG

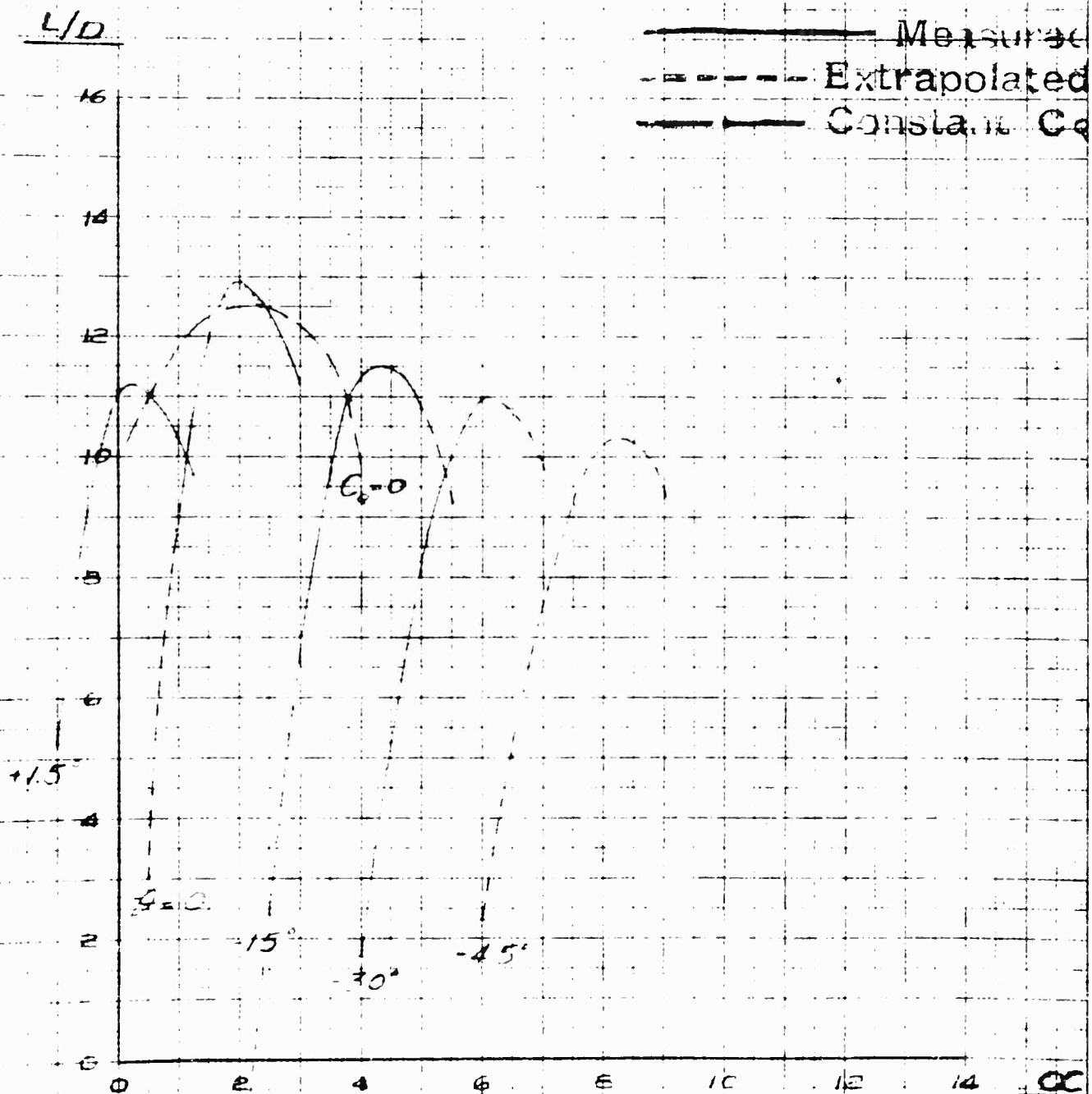
$$\mu = 1.5$$


L/D vs OC

UNAL. OCTAS TESTS
WITHOUT HUB DRAG

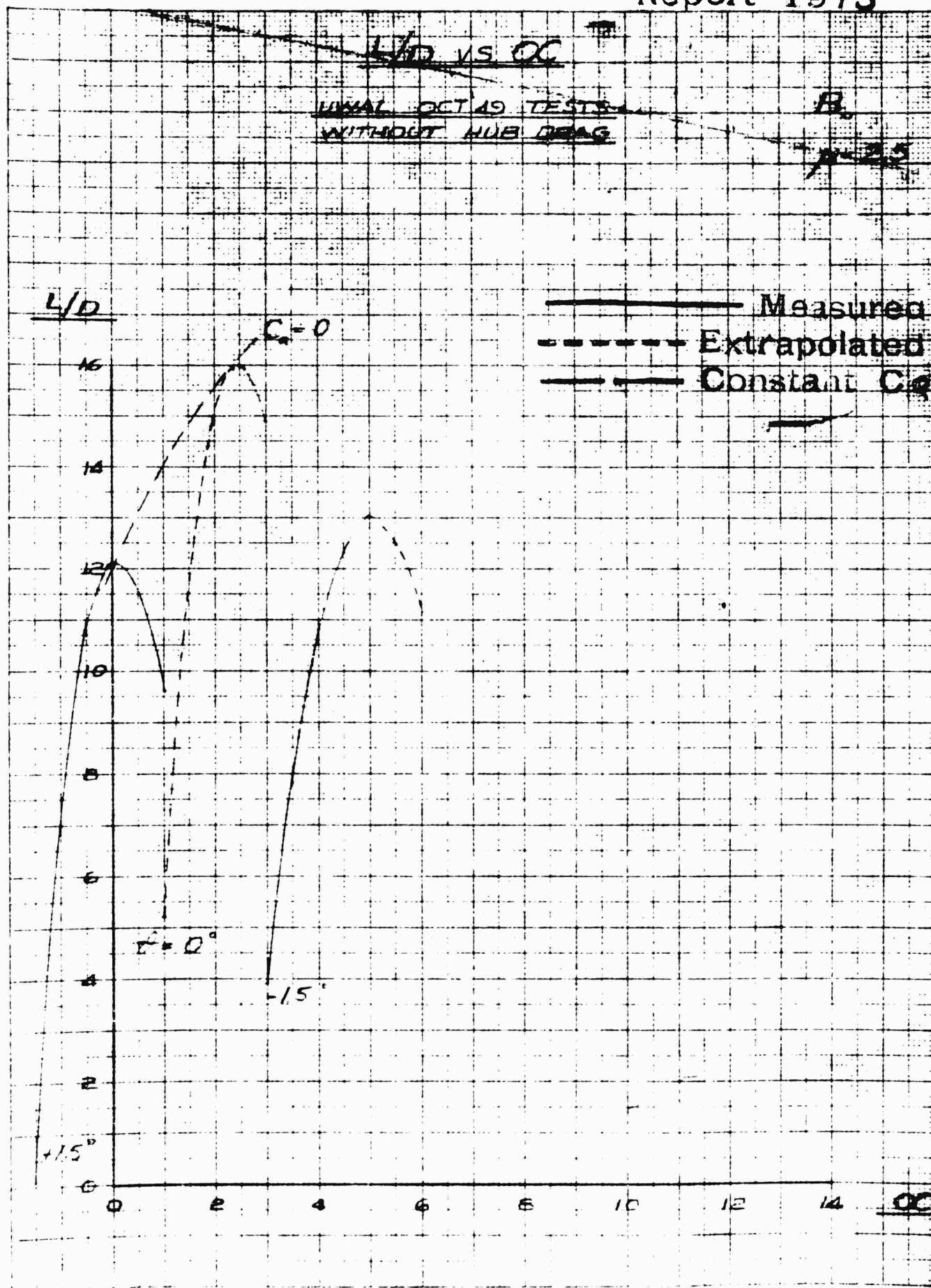
B_0

$\mu = 2.0$



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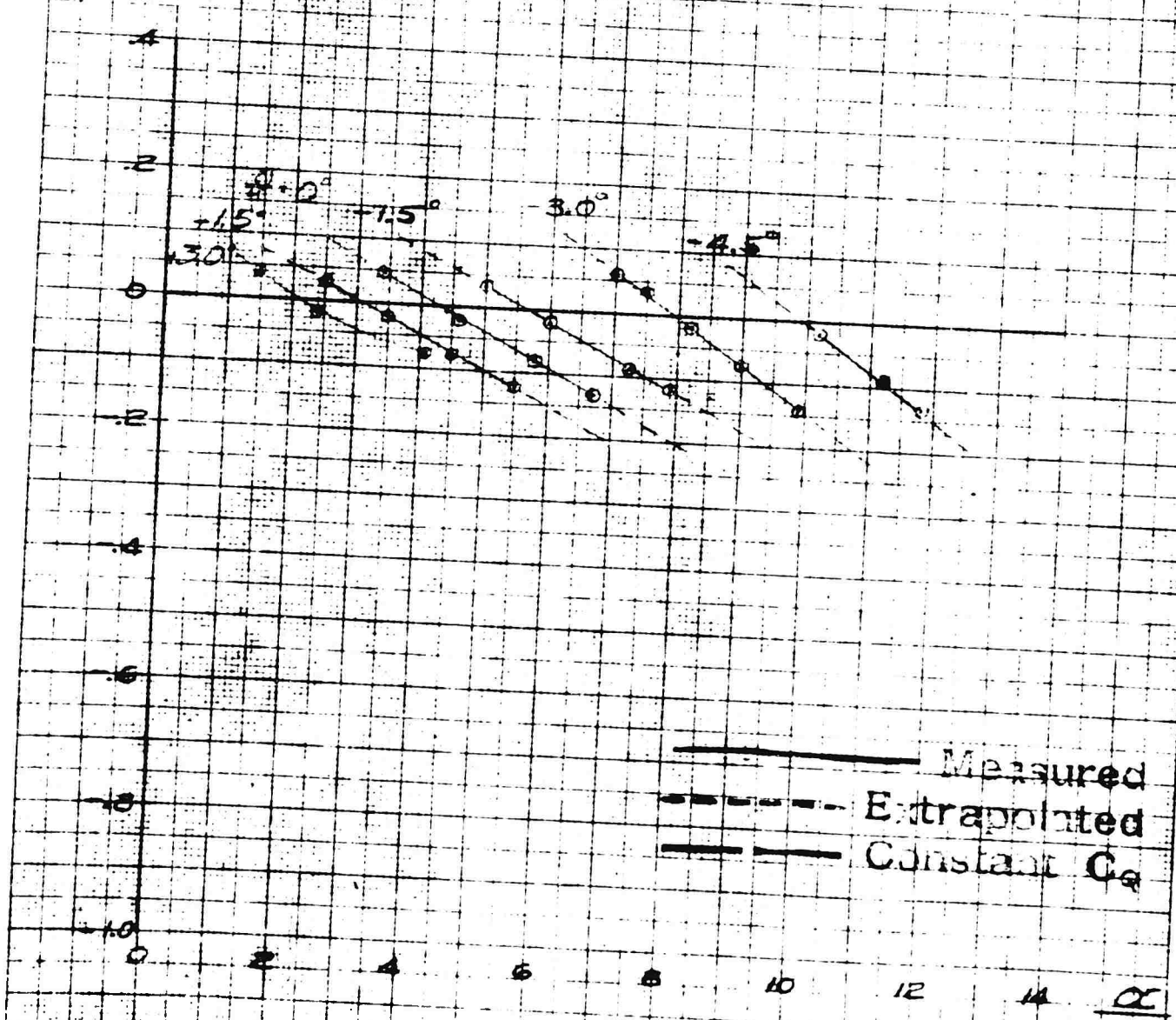


C_Q VS α

UNAL OCT '49 TESTS
WITHOUT HUB DRAG

B.
 $\mu = .5$

$10^3 C_Q$



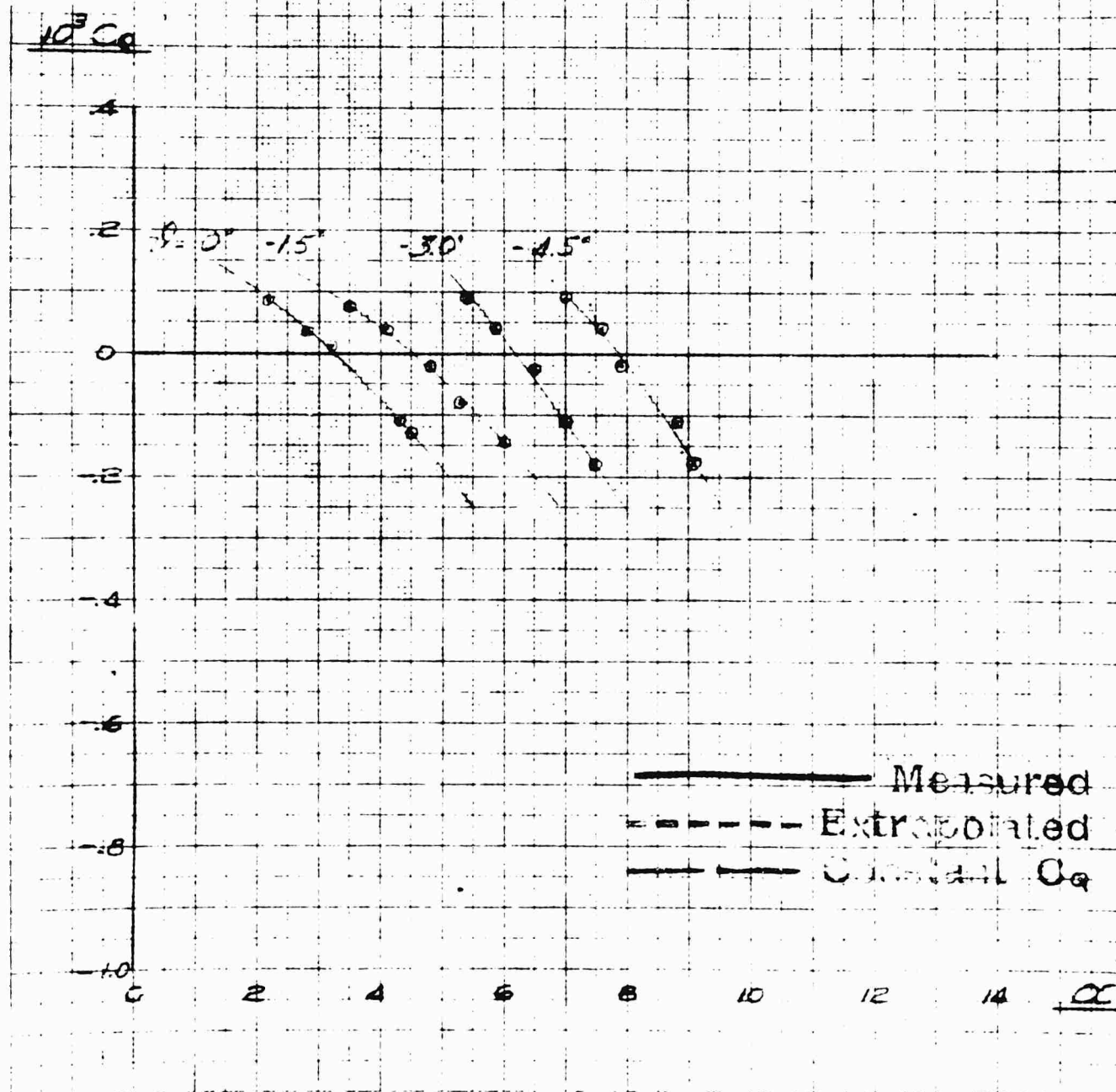
— Measured
- - - Extrapolated
— Constant C_Q

C_Q VS α

WIND TUNNEL TESTS
WITHOUT HUB DRAG

B_0

$M = .75$



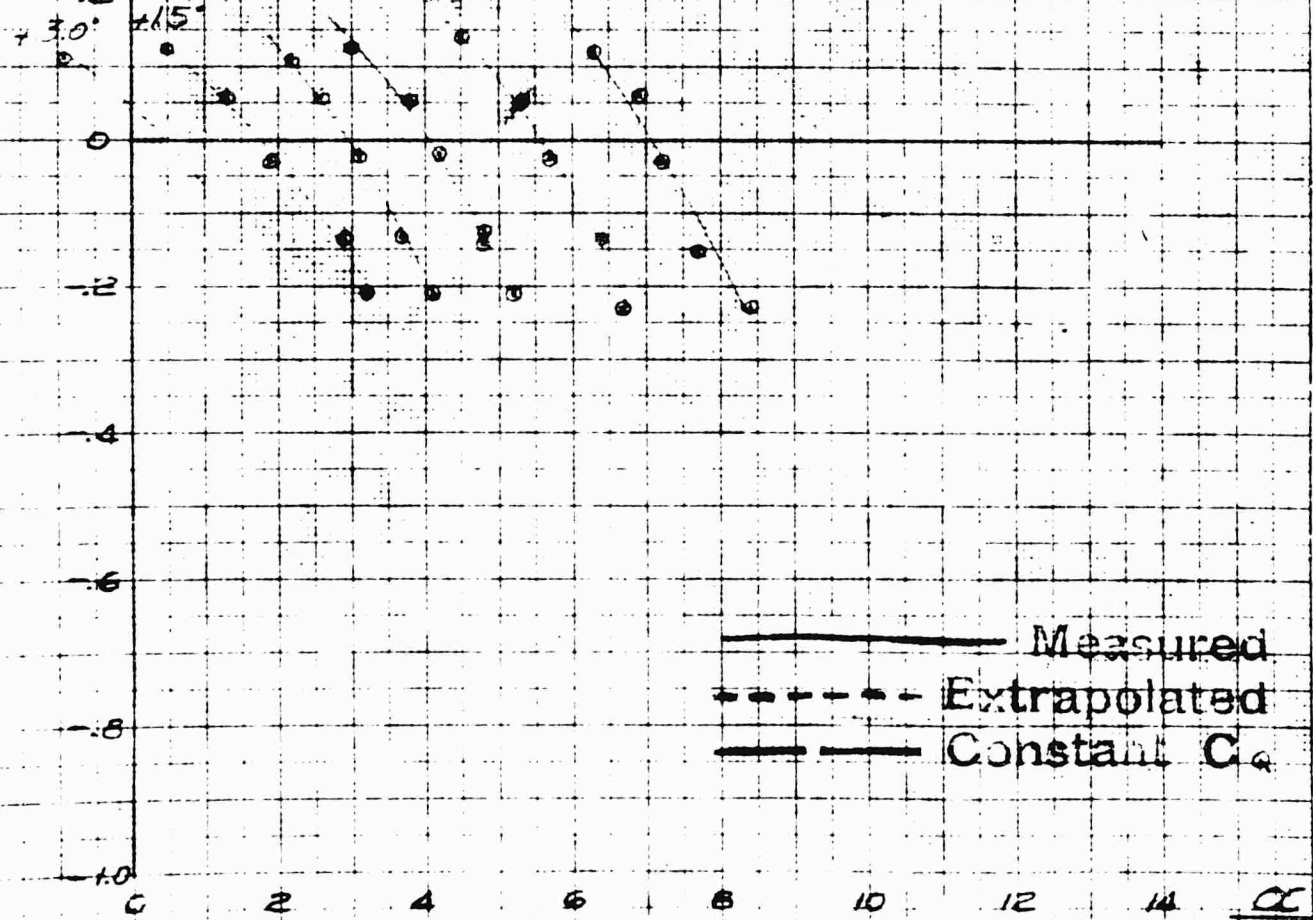
C_D vs α

UNVAL OCT '49 TESTS
WITHOUT HUB DRAG

B_0
 $\mu = 1.0$

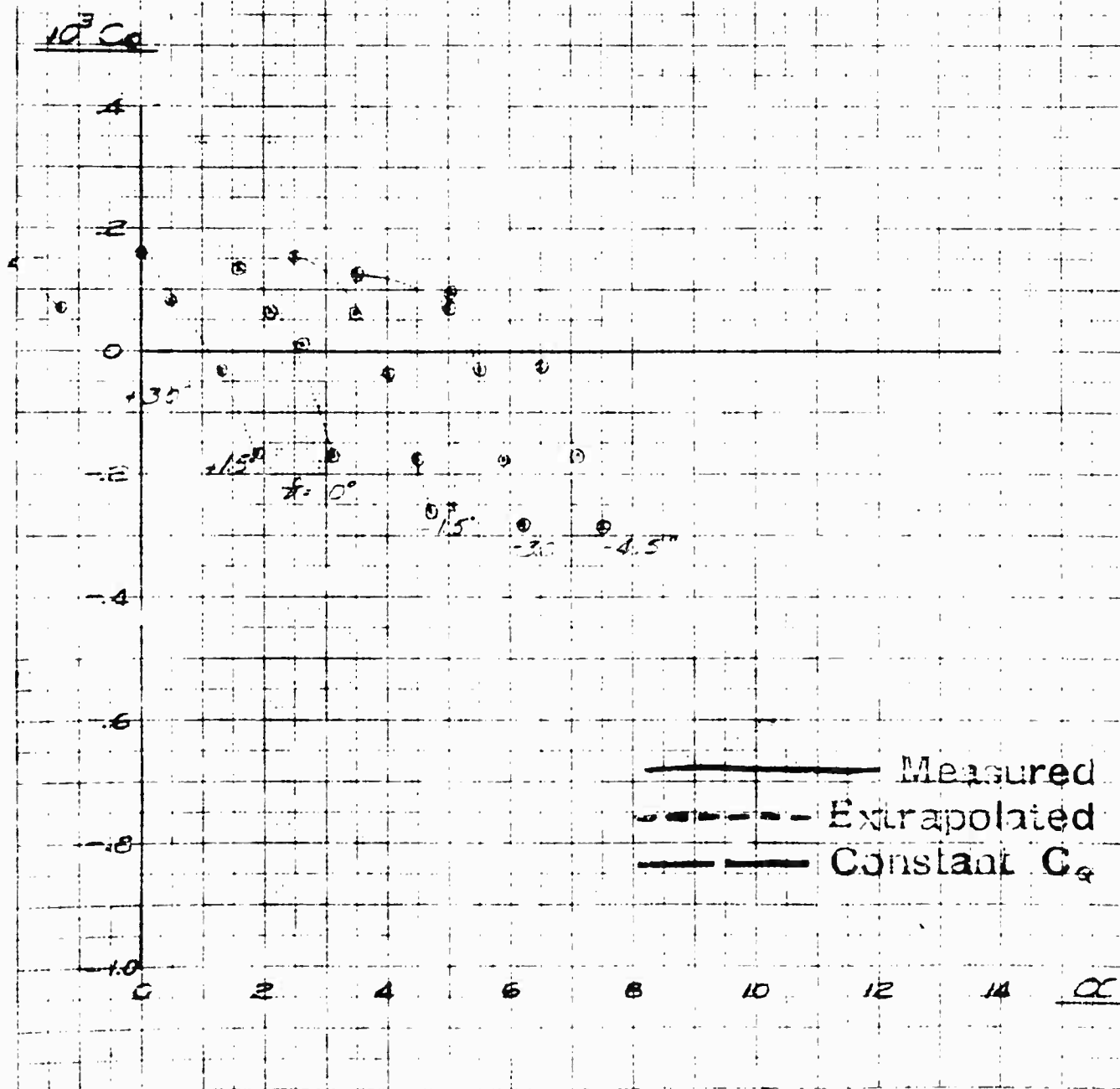
$10^3 C_D$

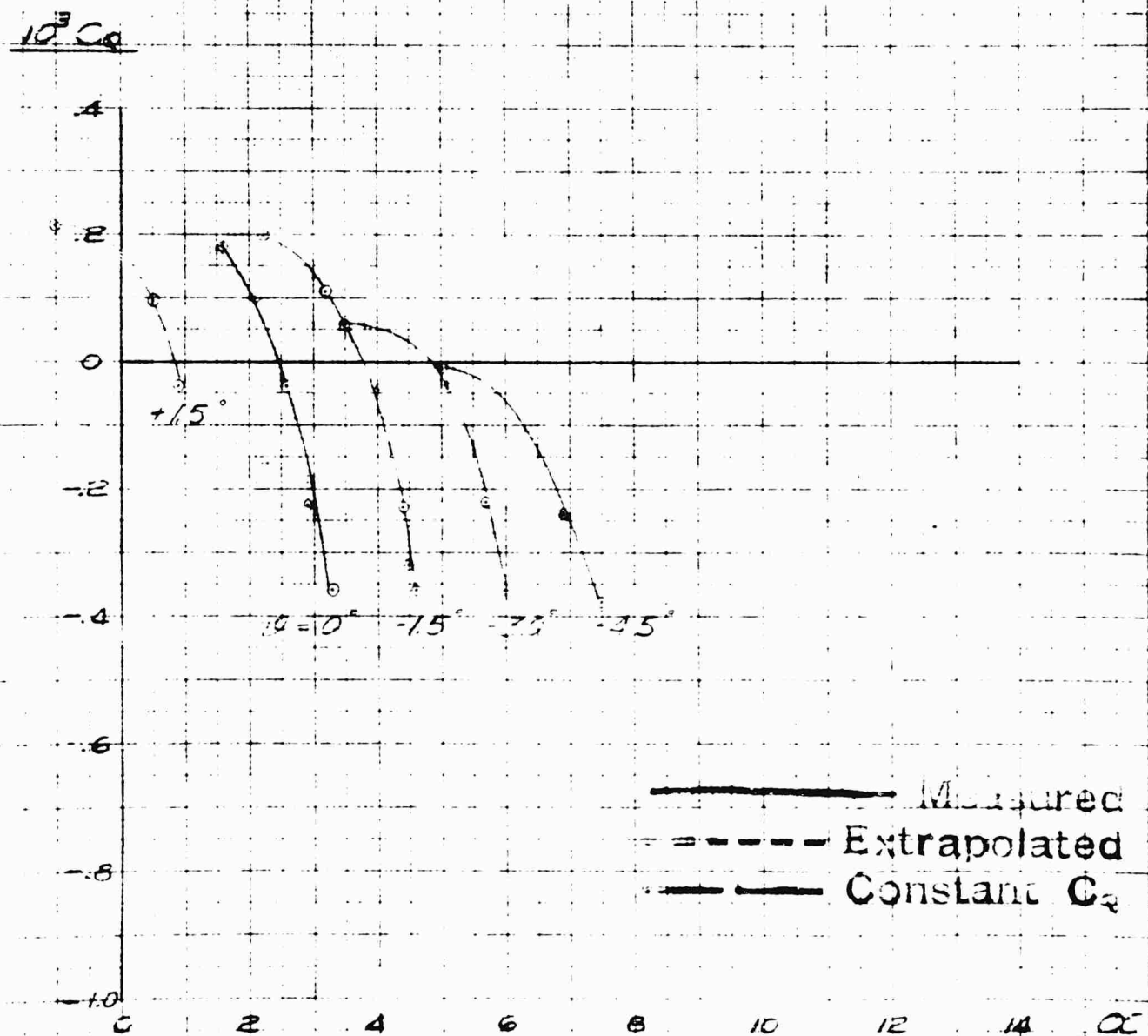
$\alpha = 0^\circ -15^\circ -30^\circ -15^\circ$



C_D VS α UNAL OLT 40 TESTS
WITHOUT HUB DRAG

B.

 $\mu = 1.25$ 

C_Q VS α UNAL OCT 42 TESTS
WITHOUT HUB DRAG B_r $\mu = 1.5$ 

C_d vs α

UNAL OCT 69 TESTS
WITHOUT HUB DRAG

B_s
 $\mu = 2.0$

$10^3 C_d$

4

2

0

-2

-4

-6

-8

-10

-12

-14

-16

-18

-20

-22

-24

-26

-28

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-538

-540

-542

-544

-546

-548

-550

-552

-554

-556

-558

-560

-562

-564

-566

-568

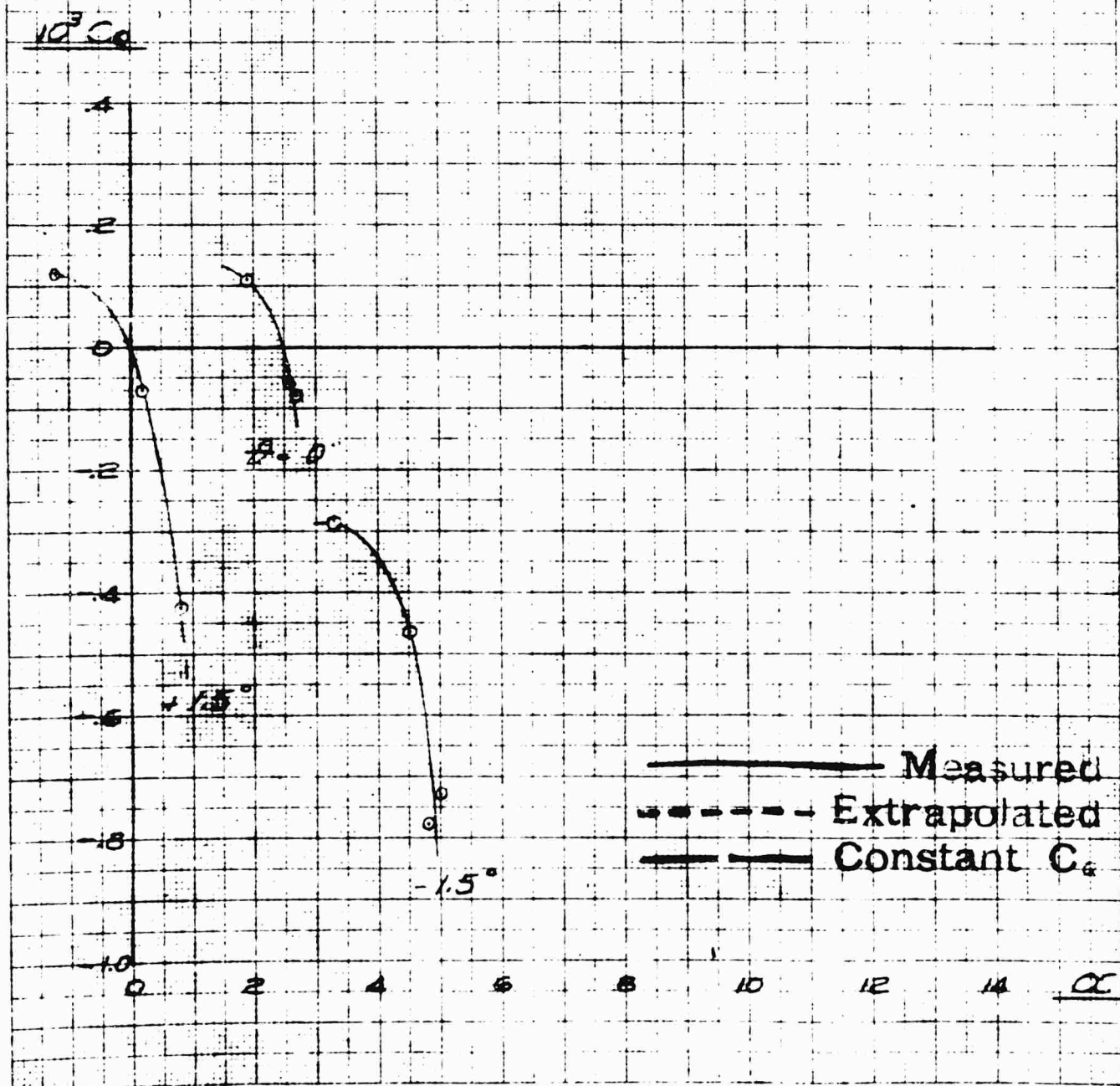
-570

-572

-574

C_D VS α UWAL OCT '49 TESTS
WITHOUT HUB DRAG

B.

 $\lambda = 2.5$ 

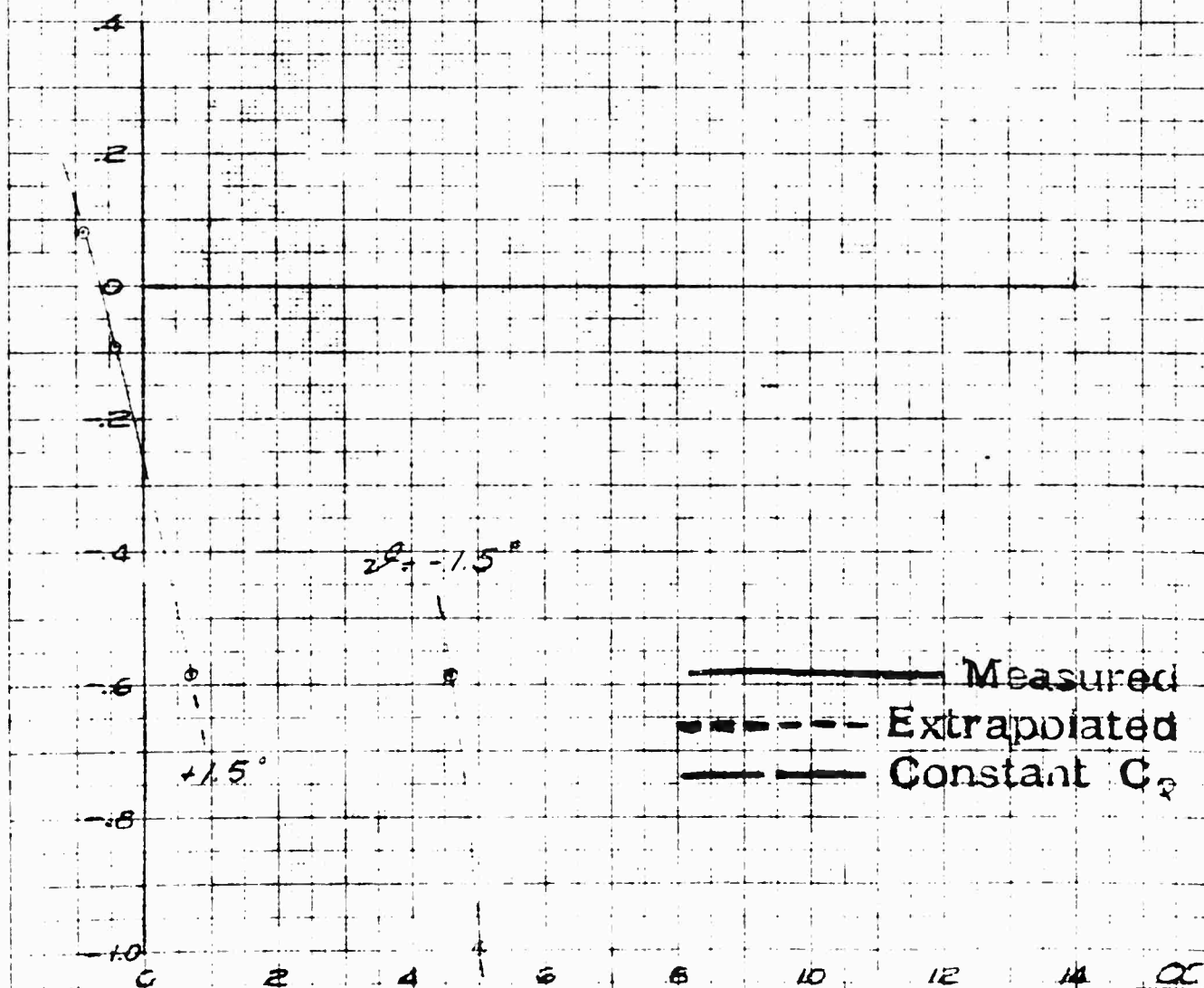
C_D VS α

UNAL CUT '42 TESTS
WITHOUT HUB DRAG

B_0

$M = 3.0$

$10^3 C_D$



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Q_1 VS α

VIVAL OCT 49 TESTS
WITHOUT HUB DRAG

B.

$\mu = .5$

Q_1

10

8

6

4

2

0

-2

-4

-6

-8

0

2

4

6

8

10

12

14

α

$\alpha = +3.0^\circ$

$+1.5^\circ$

0°

-1.5°

-2.5°

-3.0°

-3.5°

-4.0°

————— Measured
- - - - - Extrapolated
..... Constant C_q

PERFECT & FOSBERG CO.

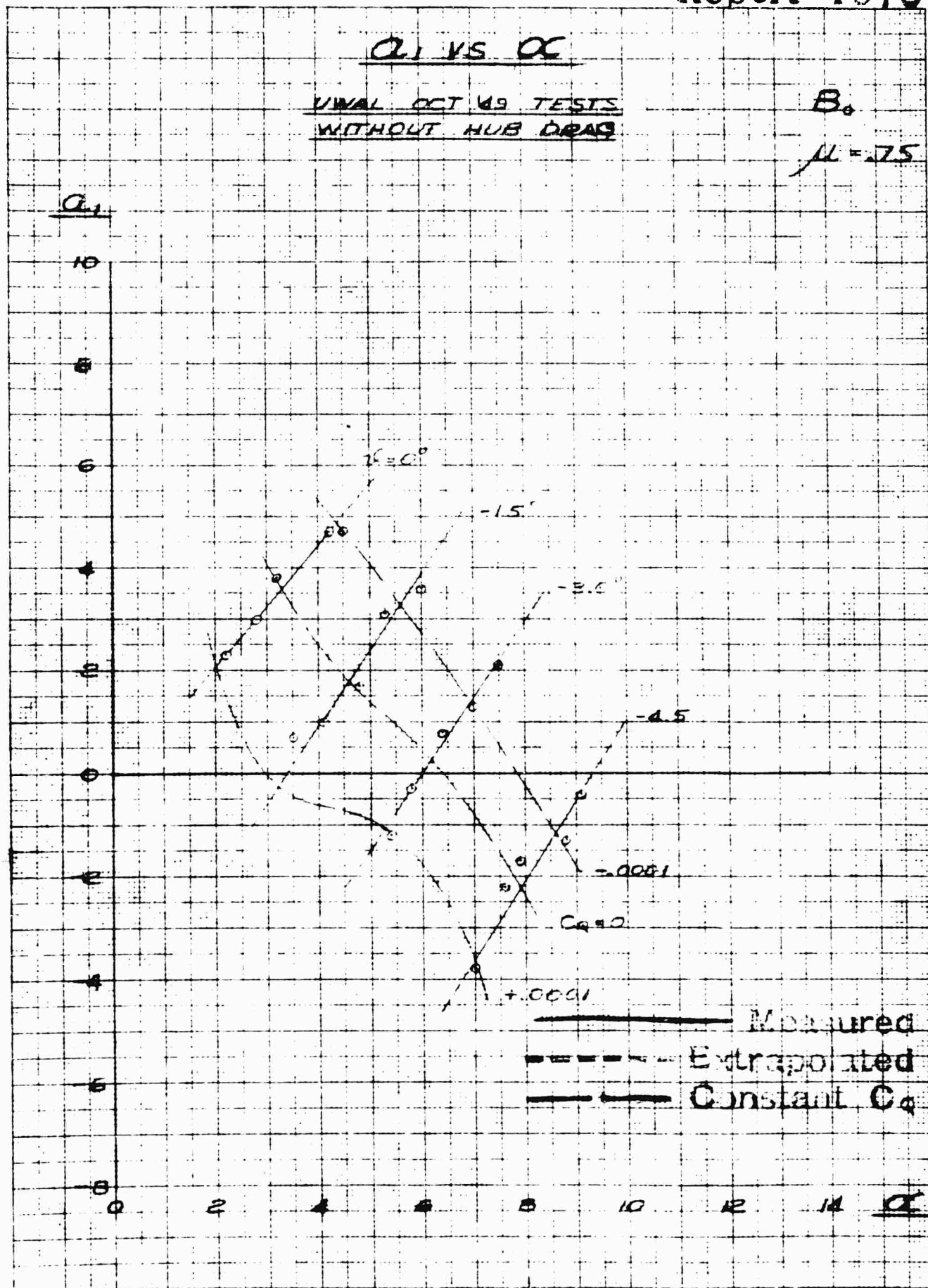
No. 349 14 Millimeter, 5 mm lines, oriented, cut, heavy

Q_1 VS α

VIVAL OCT 69 TESTS
WITHOUT HUB DRAG

B_0

$\mu = .75$

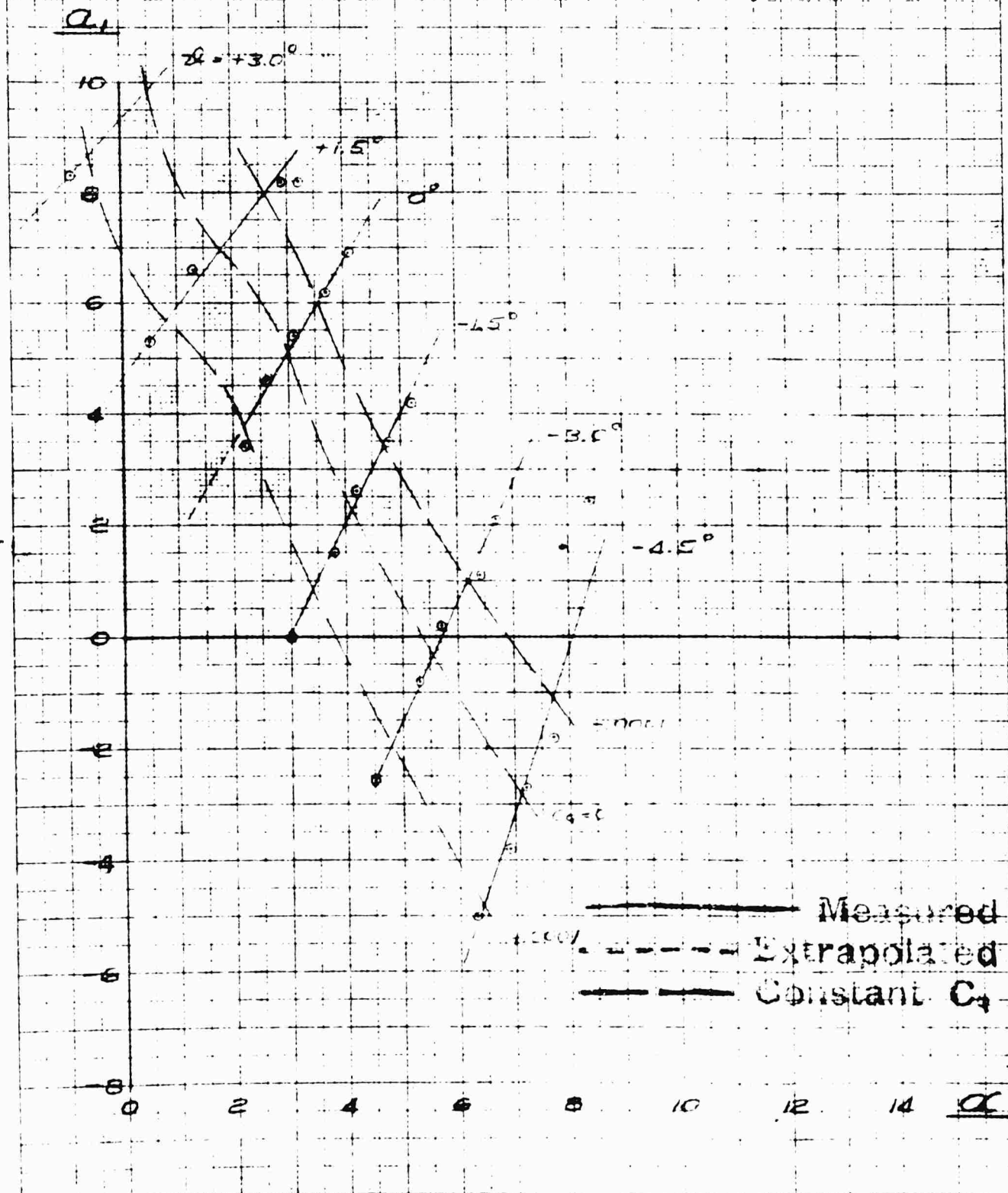


Q_L VS α

UNVAL OCT 49 TESTS
WITHOUT HUB DRAG

B_0

$\mu = 1.0$



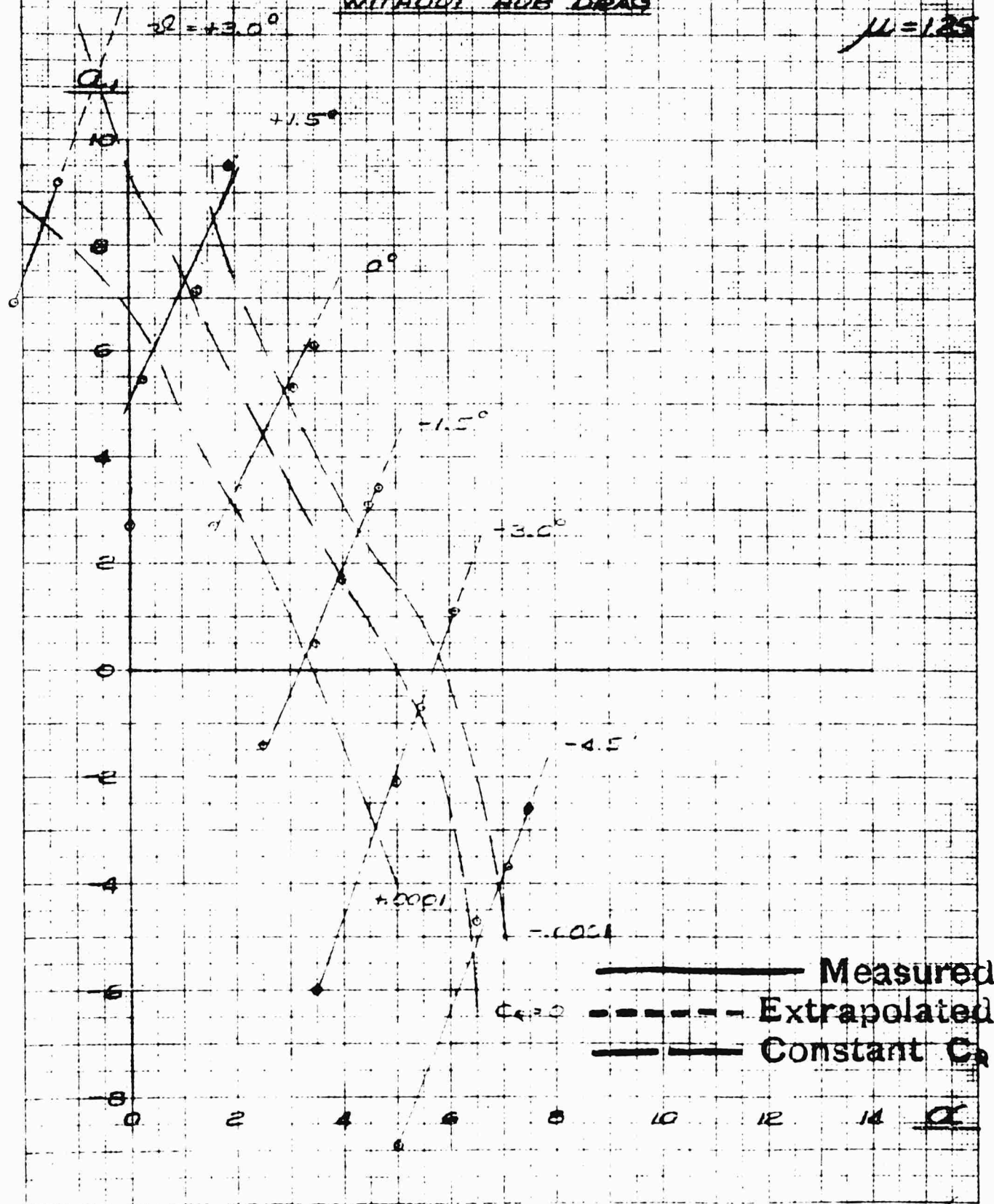
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Q_L VS α

VIVAL OCT 49 TESTS
WITHOUT HUB DRAG

B_0

$\mu = 1.25$



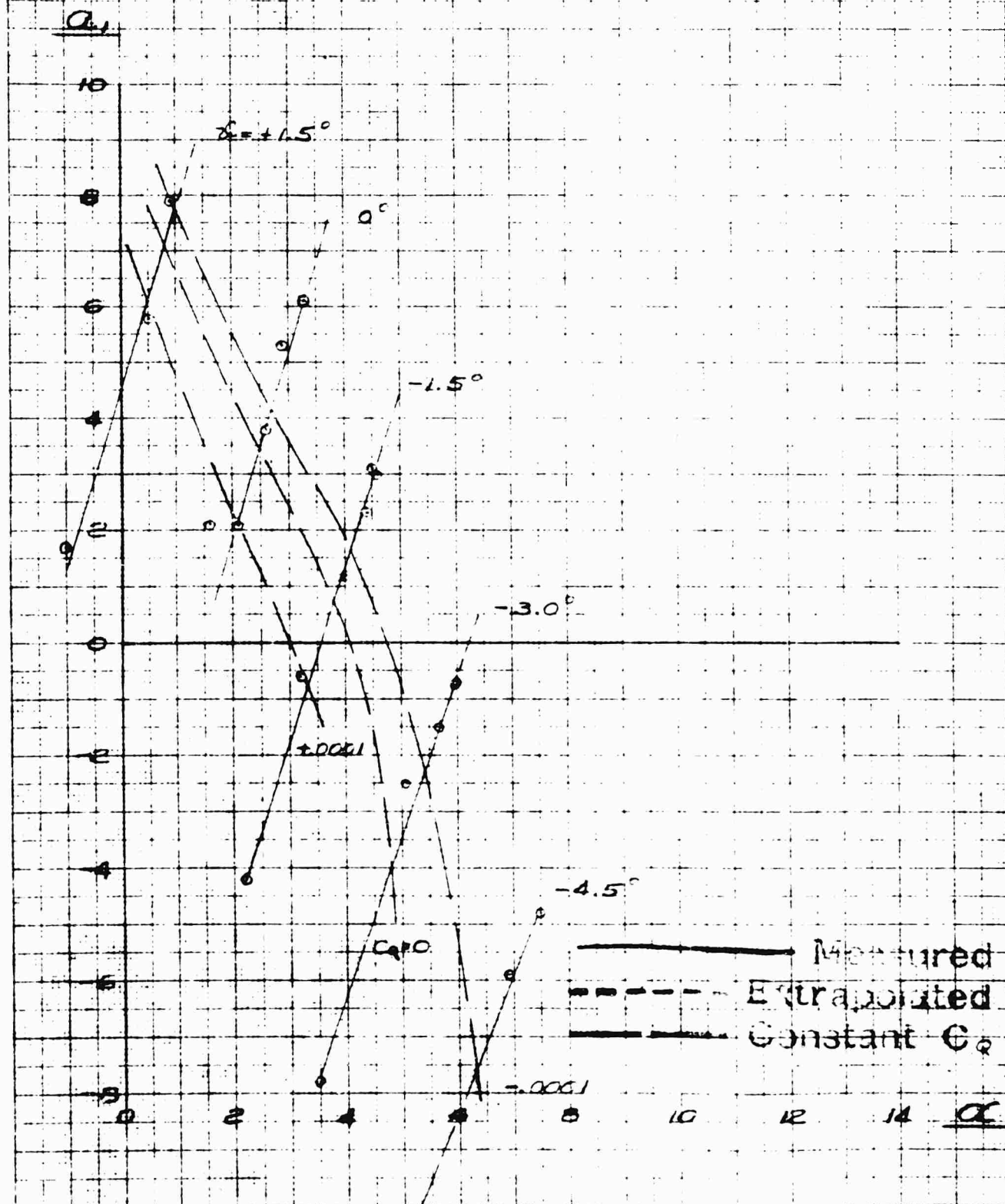
KEUFFEL & ESSER CO.

No. 31914 Millimeters, 5 mm lines a centimeter, 10 lines a decimeter.

10-11 40

Q_1 VS α

UNAL OCT 43 TESTS
WITHOUT HUB DRAG

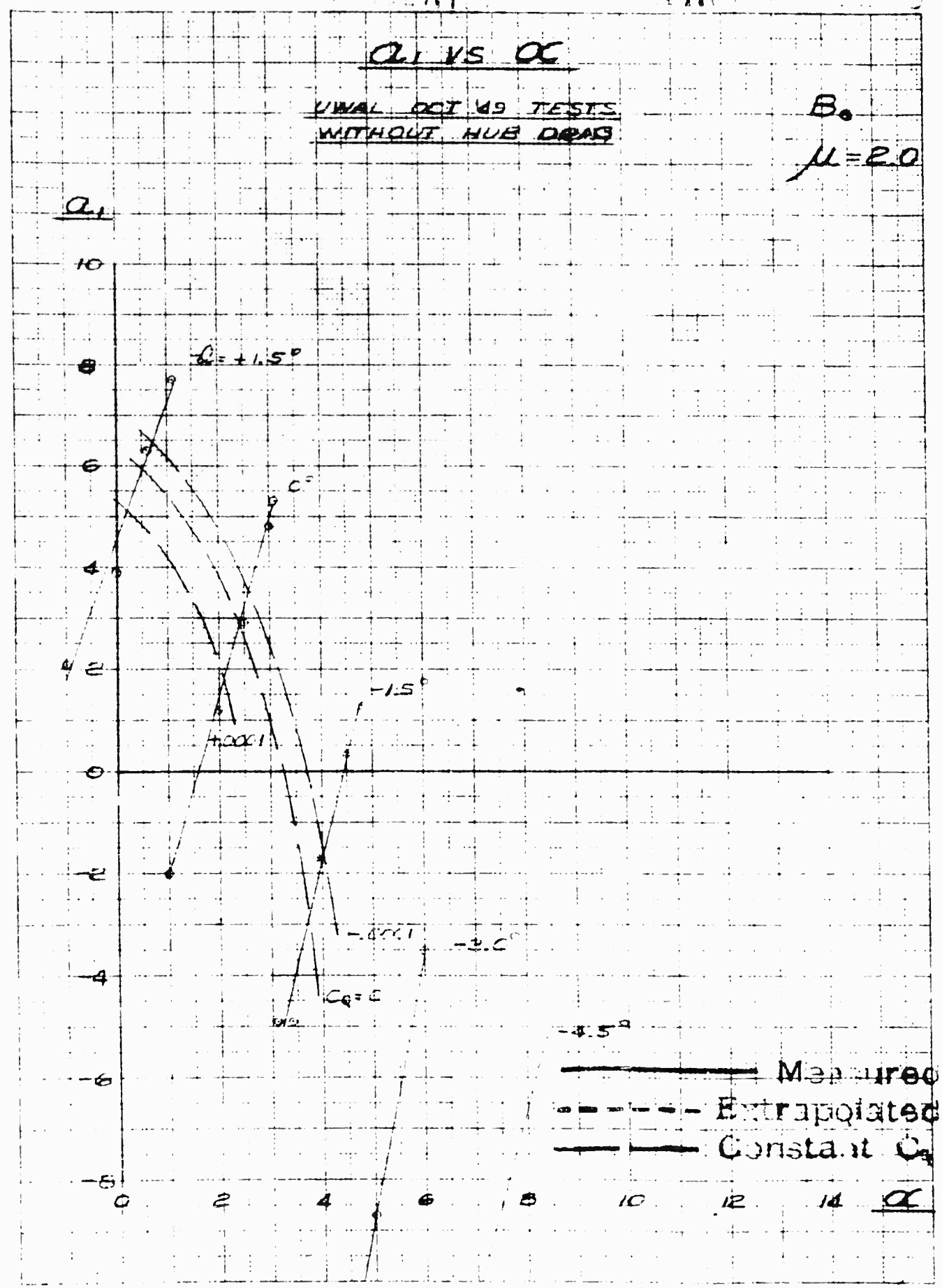
 B_0 $\mu = 1.5$ 

a_1 VS α

UWAL OCT 49 TESTS
WITHOUT HUB DRAG

B.

$\mu = 2.0$

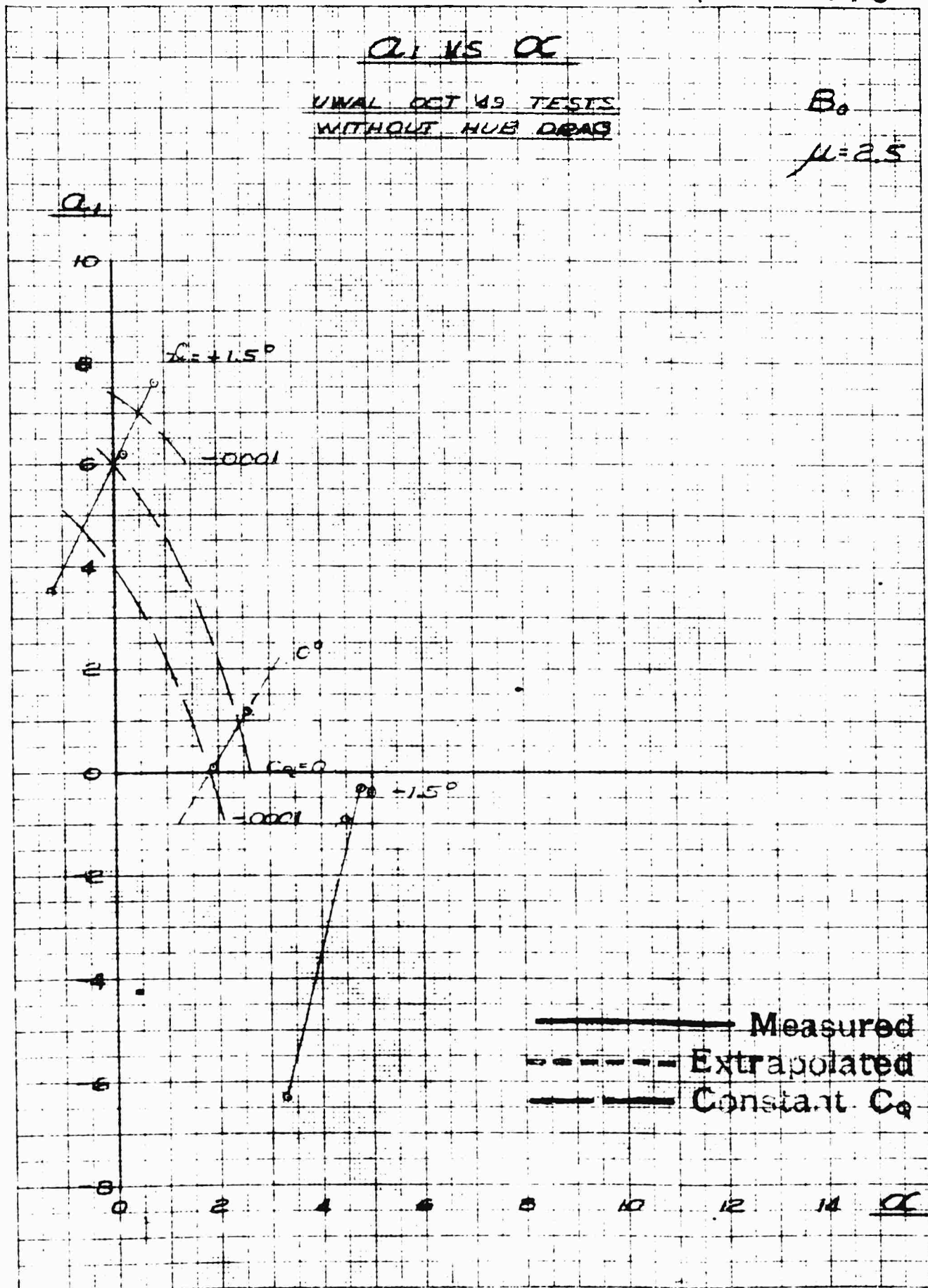


Q_L VS α

UWAL OCT 49 TESTS
WITHOUT HUE DRAG

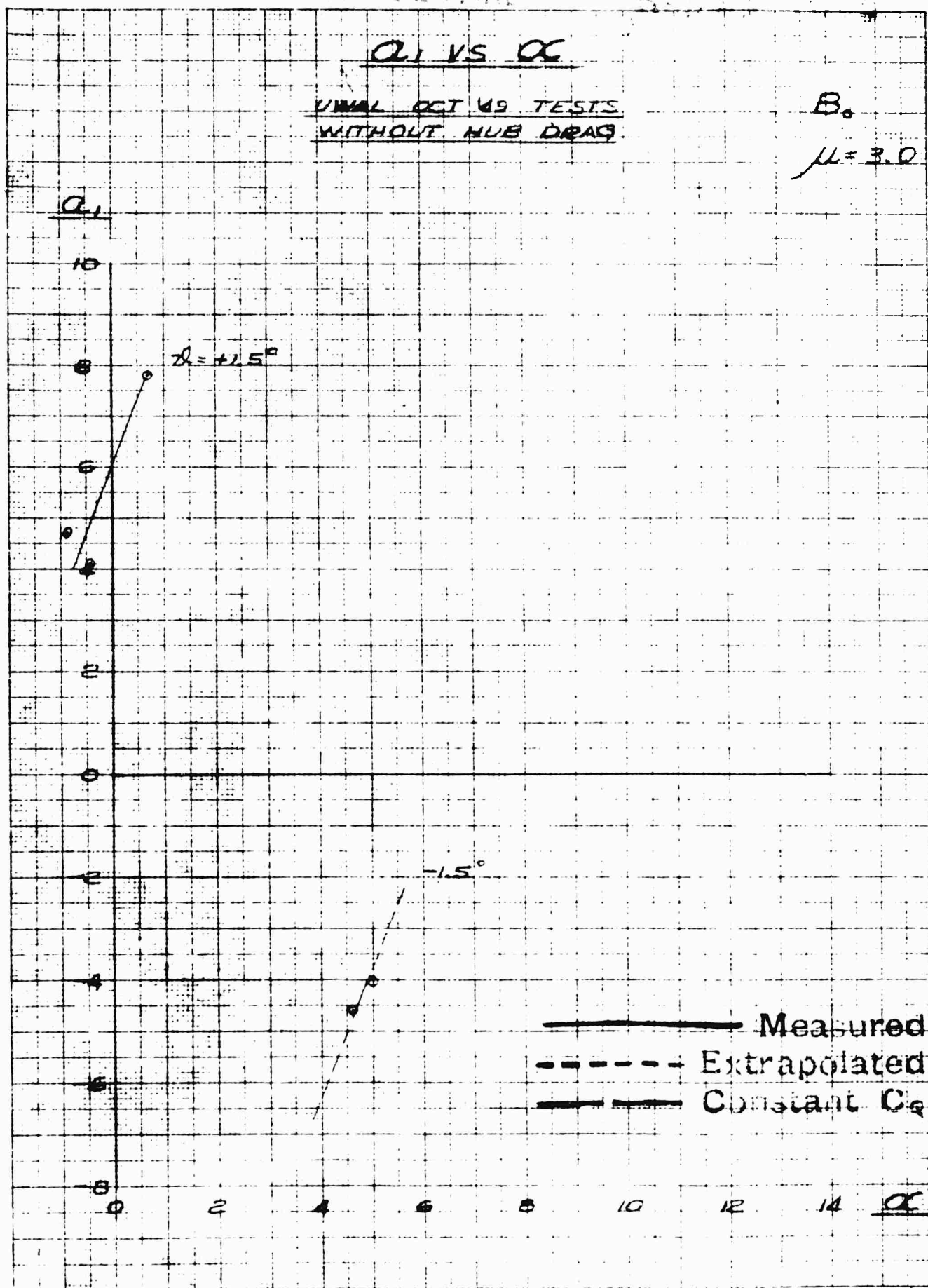
B_0

$\mu = 2.5$



KUFFEL & EUSER CO.

No. 359-14 Millimeters, 5 inch type, centered, cut lines heavy

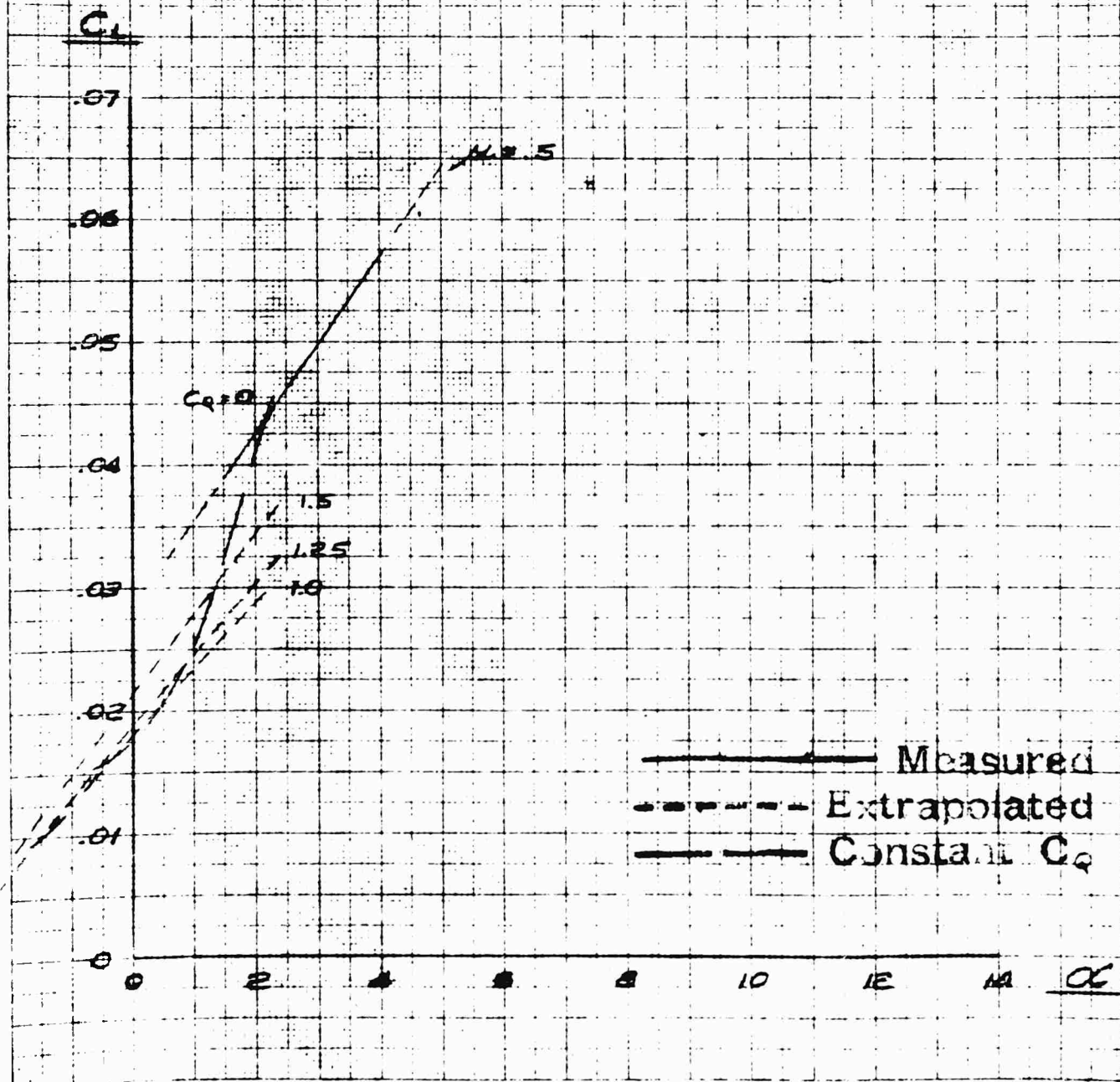


CL VS OC

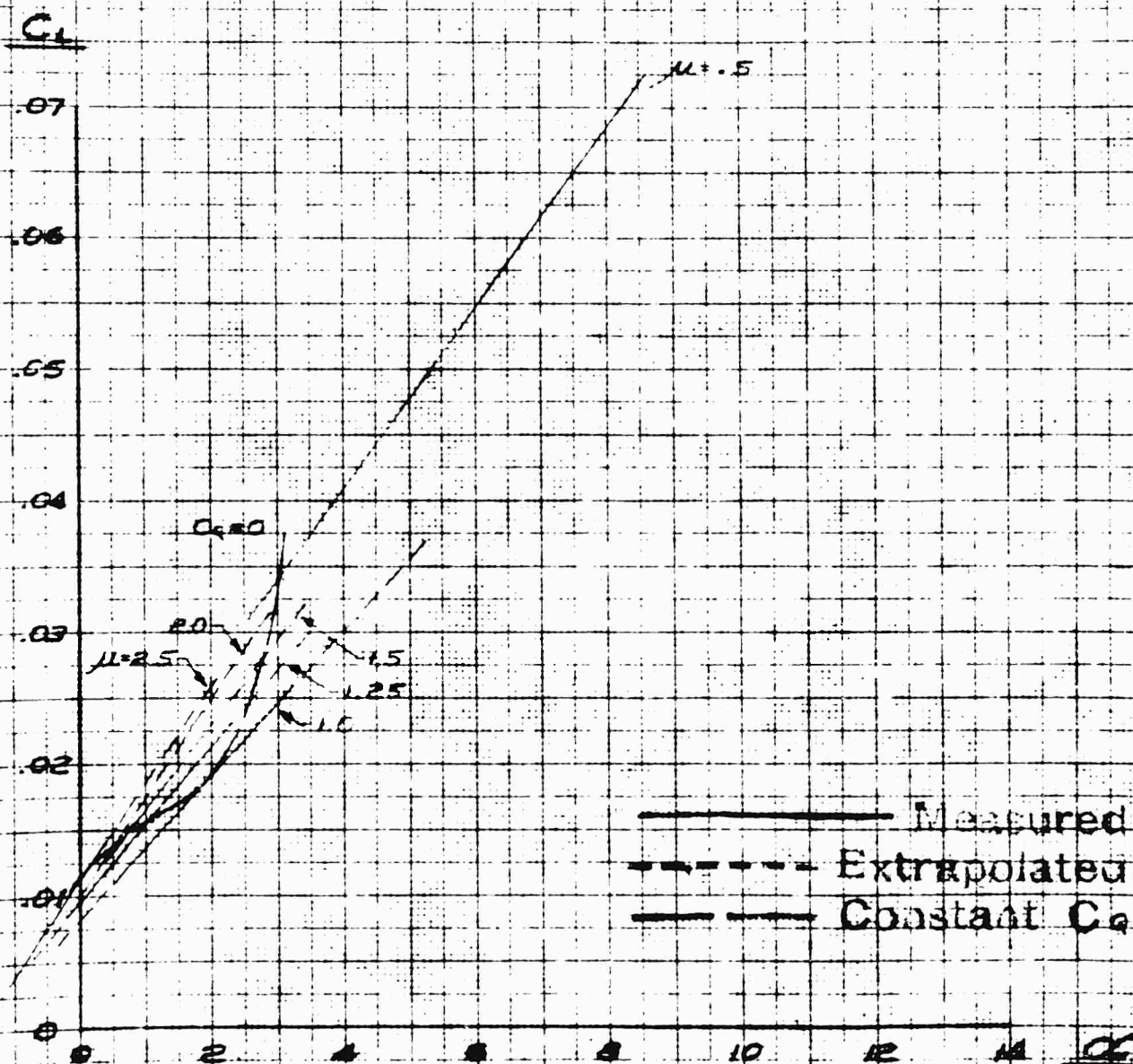
UNVAL OCT 49 TESTS
WITHOUT HUB DRAG

B₀

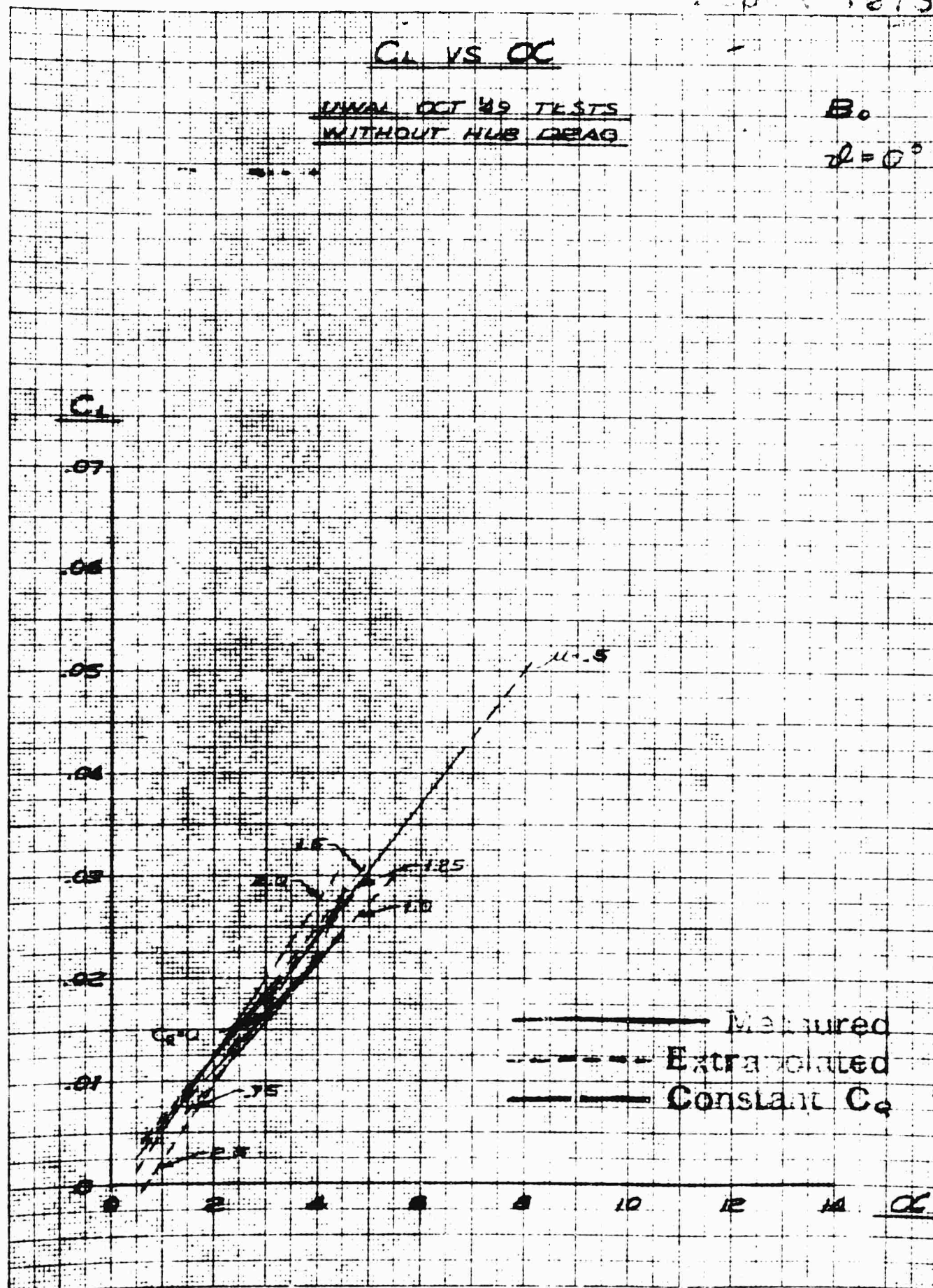
$\theta = +3.0^\circ$



R. 1000 1925

CL VS OCUNVAL OCT 49 TESTS
WITHOUT HUB DEAG B_0 $\delta = +1.5^\circ$ 

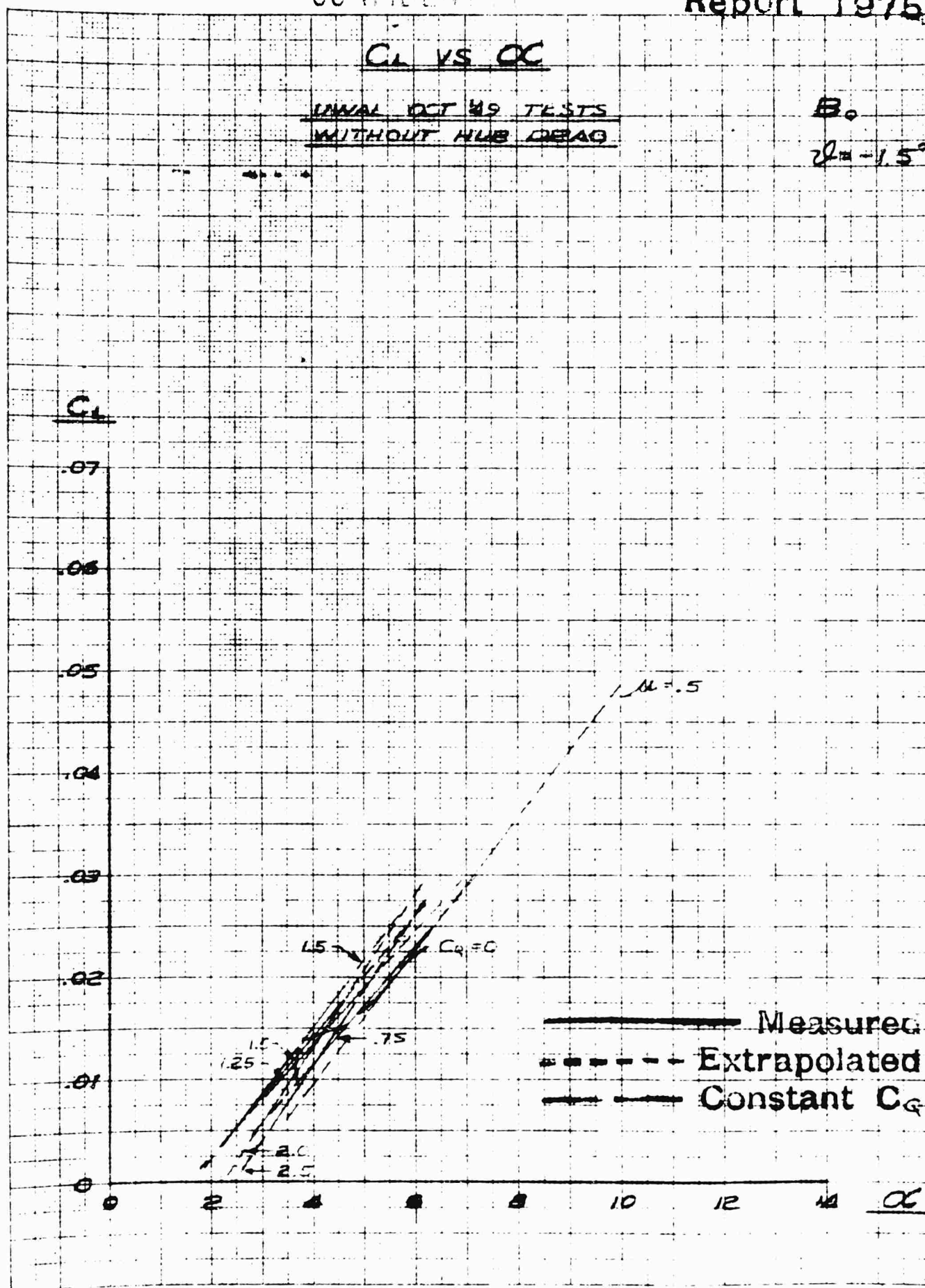
SEP 1975

 C_L VS C_D UNVAL OCT 49 TESTS
WITHOUT HUB DRAG B_0 $\alpha = 0^\circ$ 

CL VS OC

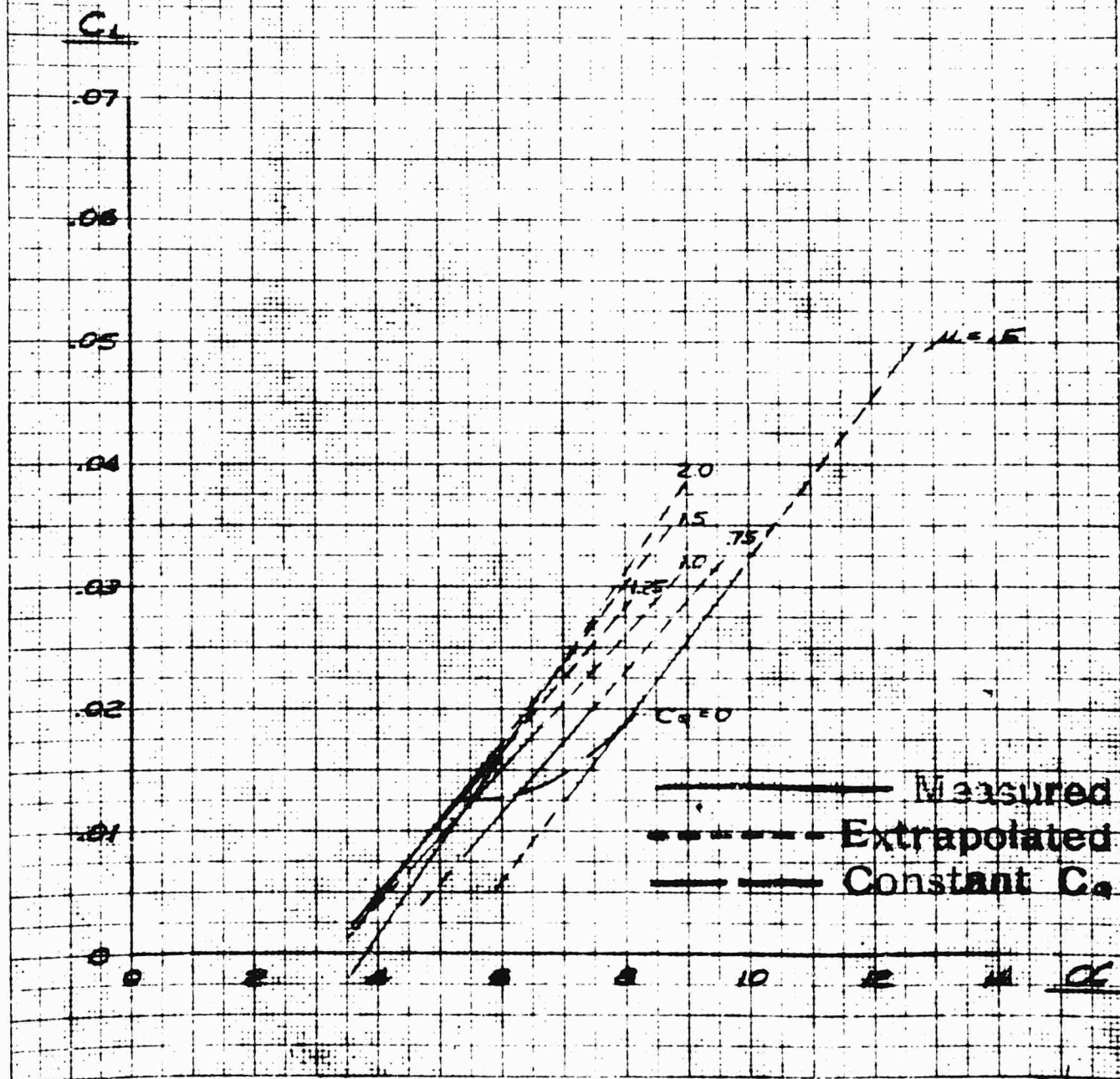
UNVAL OCT 49 TESTS
WITHOUT HUB DRAG

B.

$$\alpha = 1.5^\circ$$


CL VS CC

UWAL OCT 49 TESTS
WITHOUT HUB DEAG

$$\alpha = -3.0^\circ$$


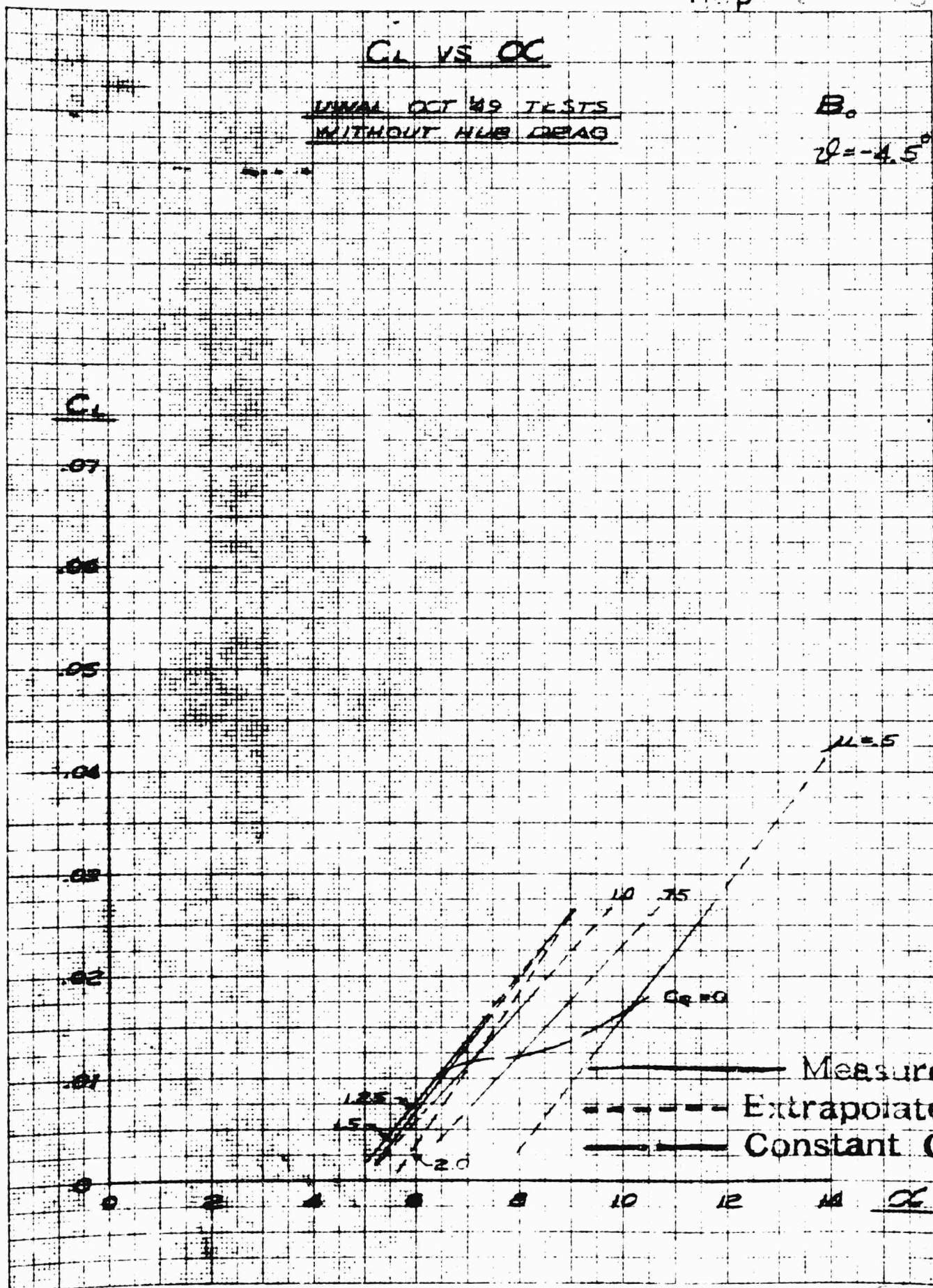
12-18-47 49

CL VS OC

UNVAL OCT 49 TESTS
WITHOUT HUB DEAG

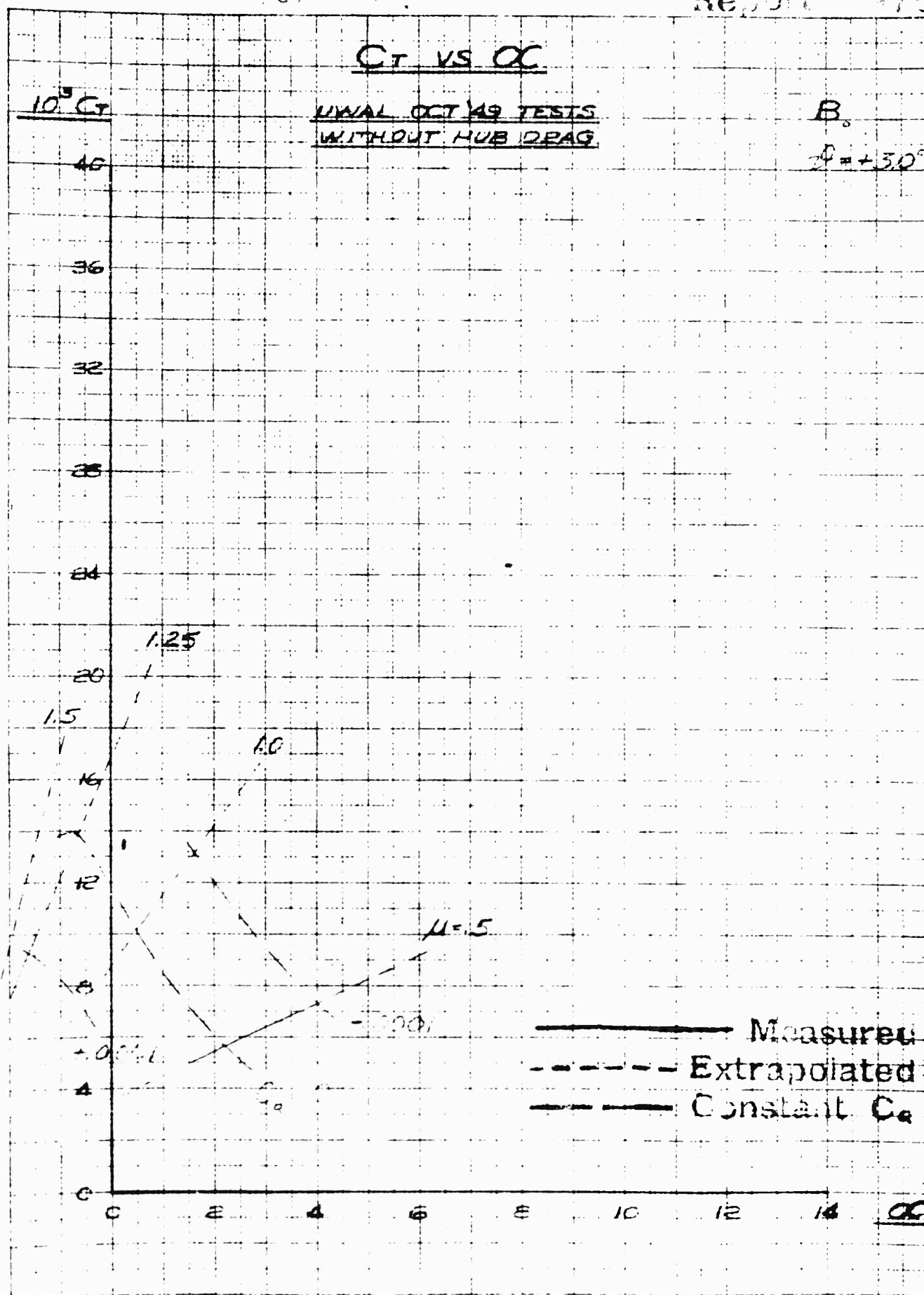
B.

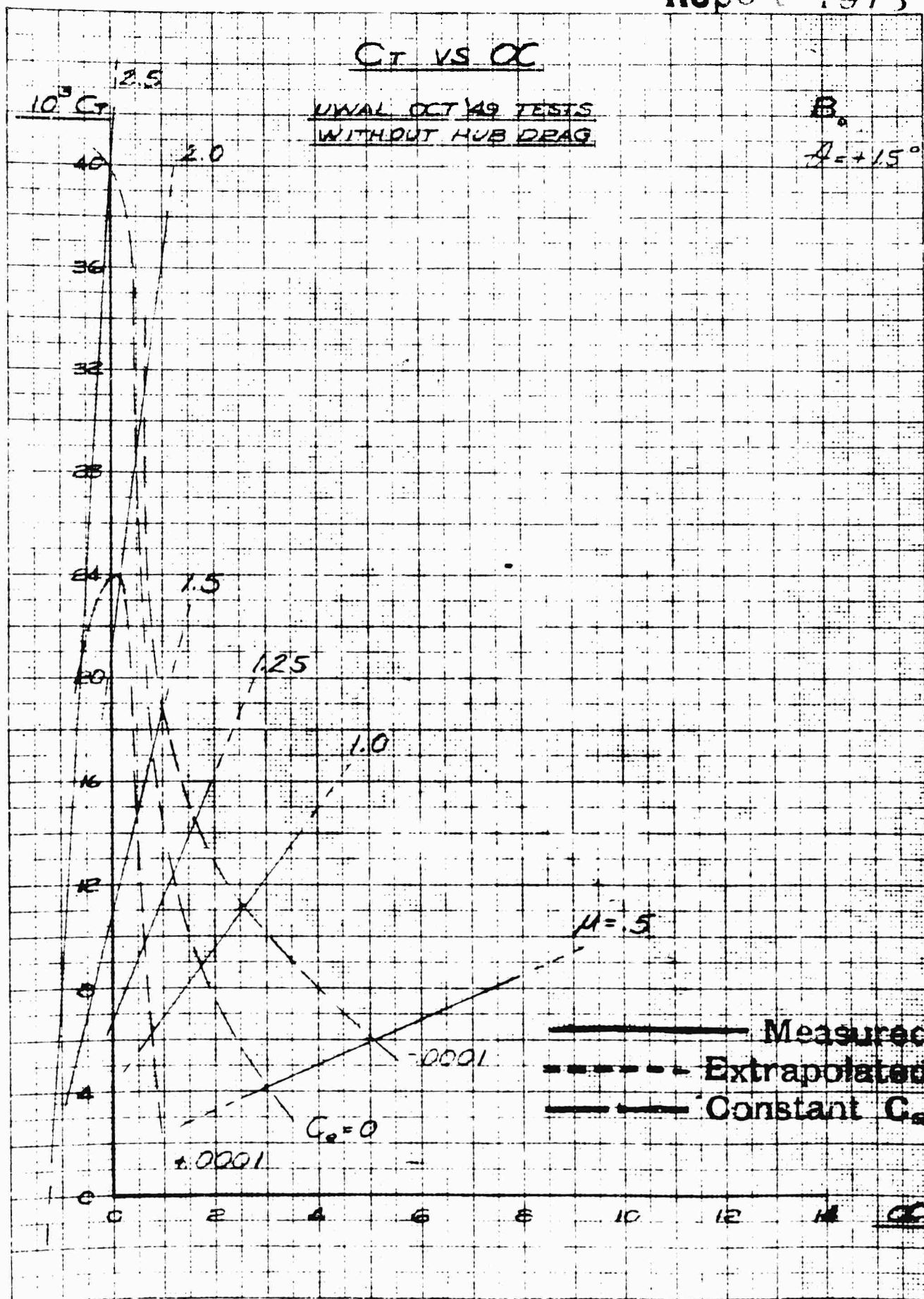
$\alpha = -4.5^\circ$



KEUFFEL & ESSER CO.

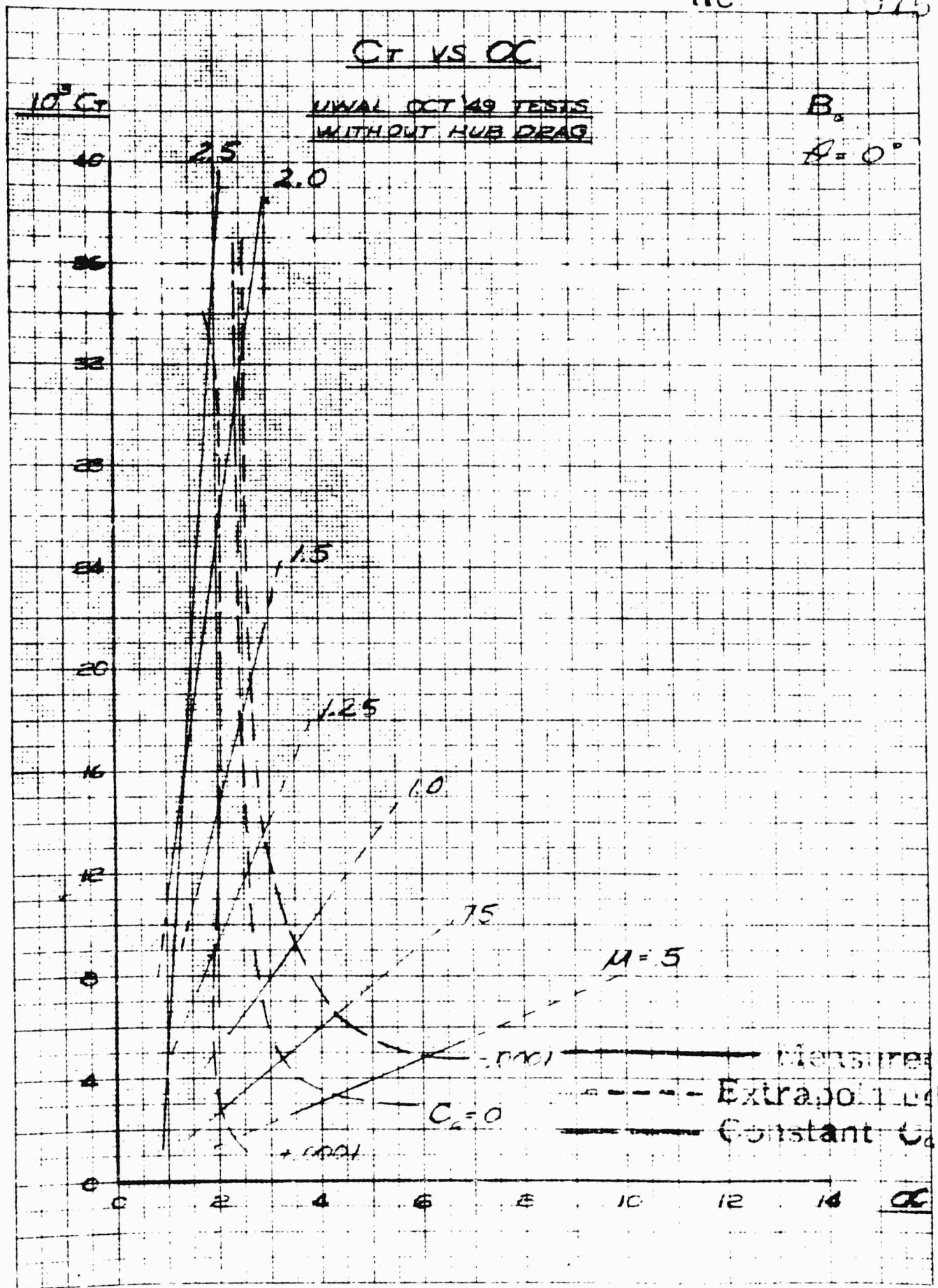
No 359 14 Millimeter 5 mm lines accepted in lines heavy





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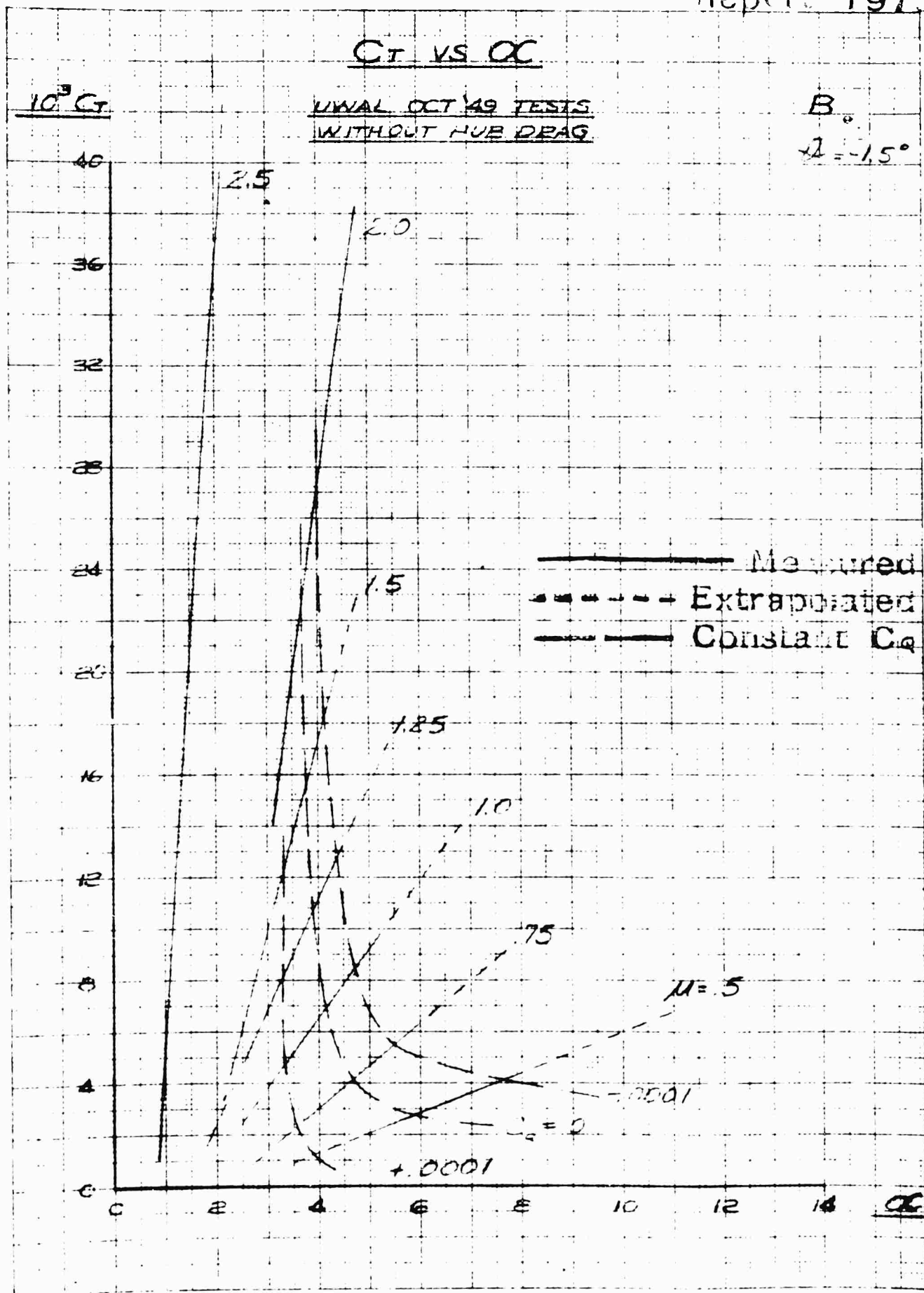


KEUFFEL & ESSER CO.

No 379 14. Millimeters, 5 mm lines accented, cm lines heavy.

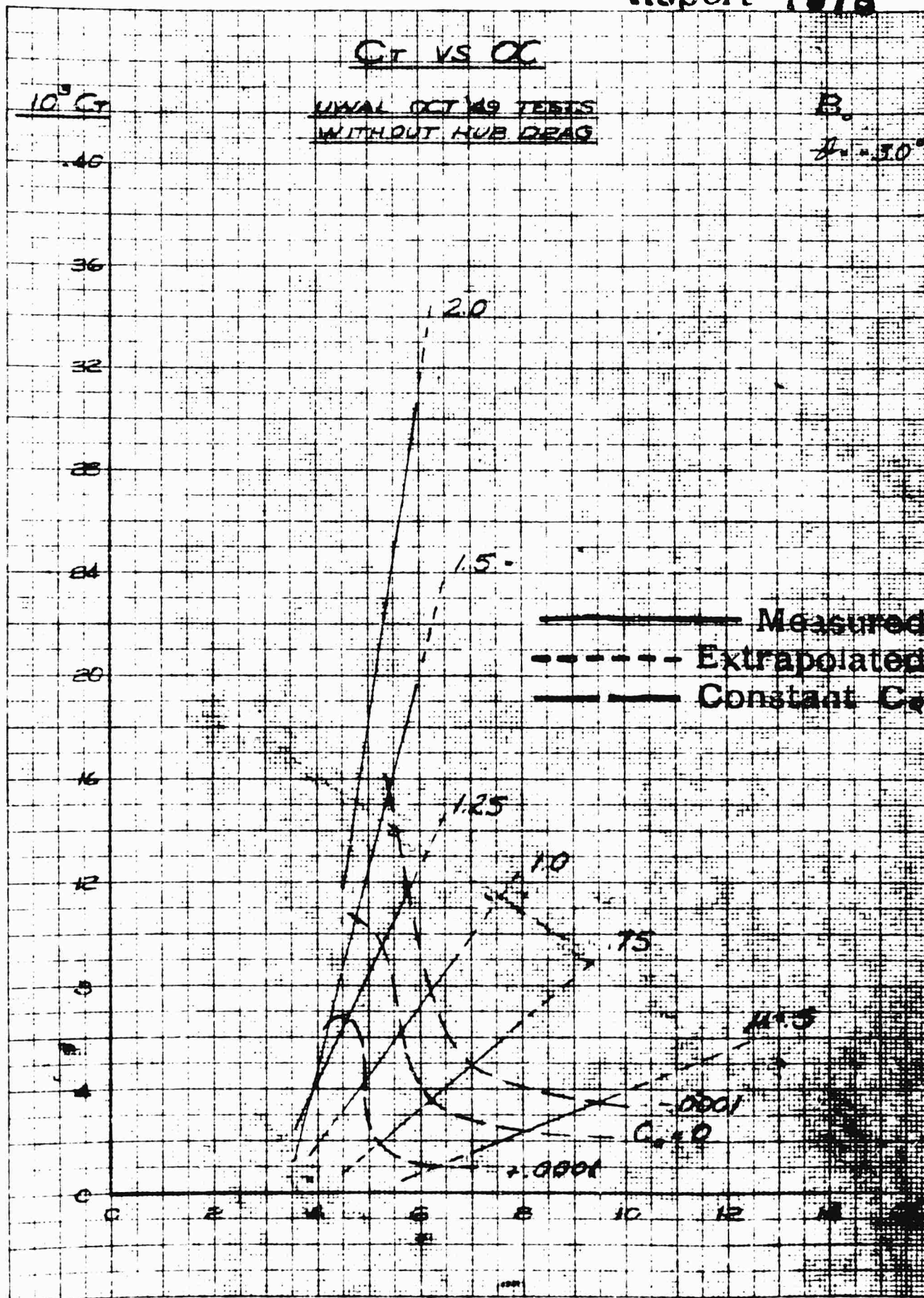
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RC5
12-14-02

55

KEUFFEL & ESSER CO.

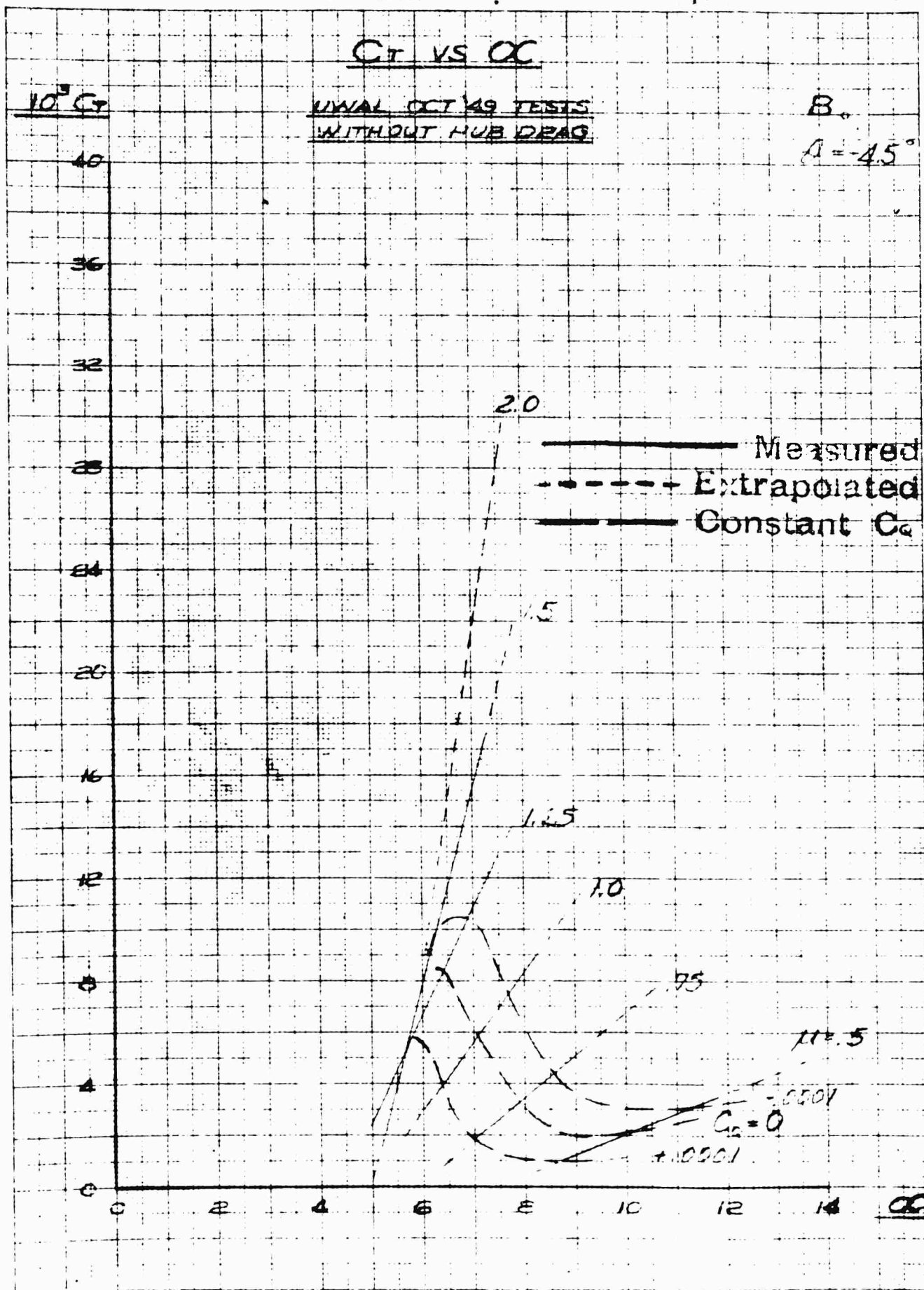
No 359-14. Millimeter, 5 mm lines are ruled on line: heavy

CT VS OC

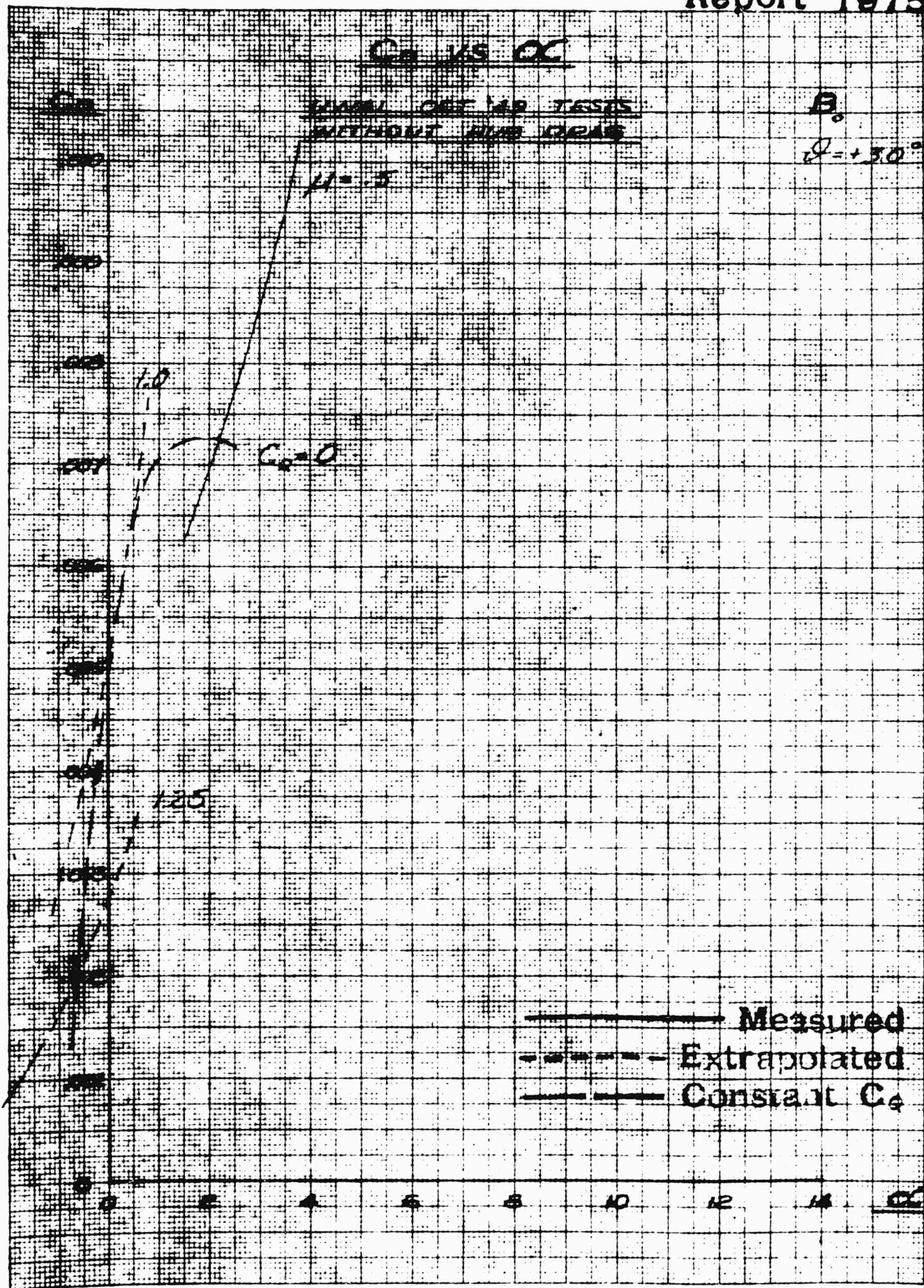
UNVAL OCT 49 TESTS
WITHOUT HUB DRAG

B.

$\Delta = -45^\circ$



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CLASS

ANAL GET 49 TESTS
WITHOUT ANY DEAG

 2×1.5

WHS

375

中国

100-1000

Measured
Extrapolated
Constant C

KEUFFEL & ESSER CO.

No. 35-14. Infundibula, 8 mm lines accented, cm lines heavy.

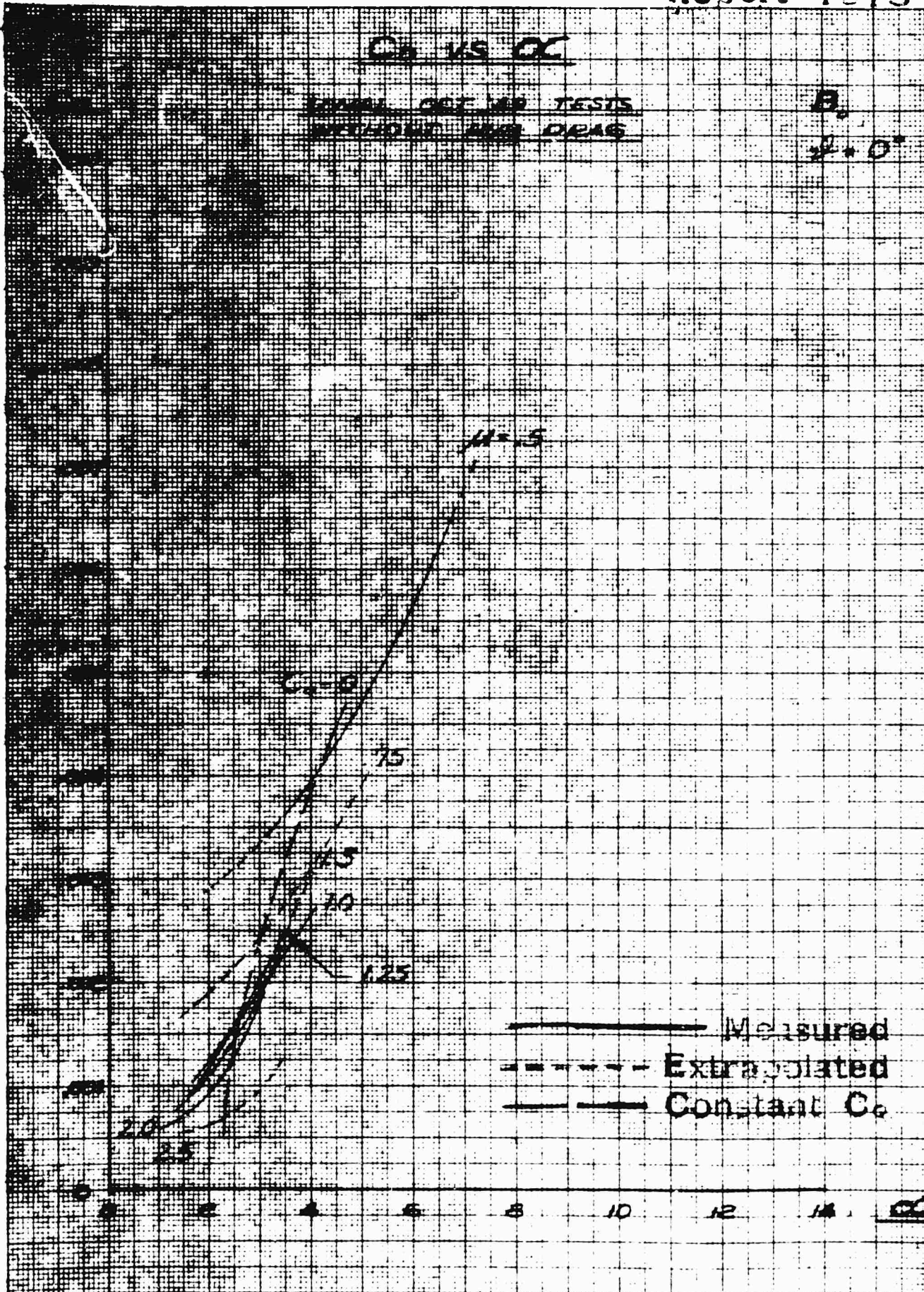
HC
12-14-87

58

007-10000

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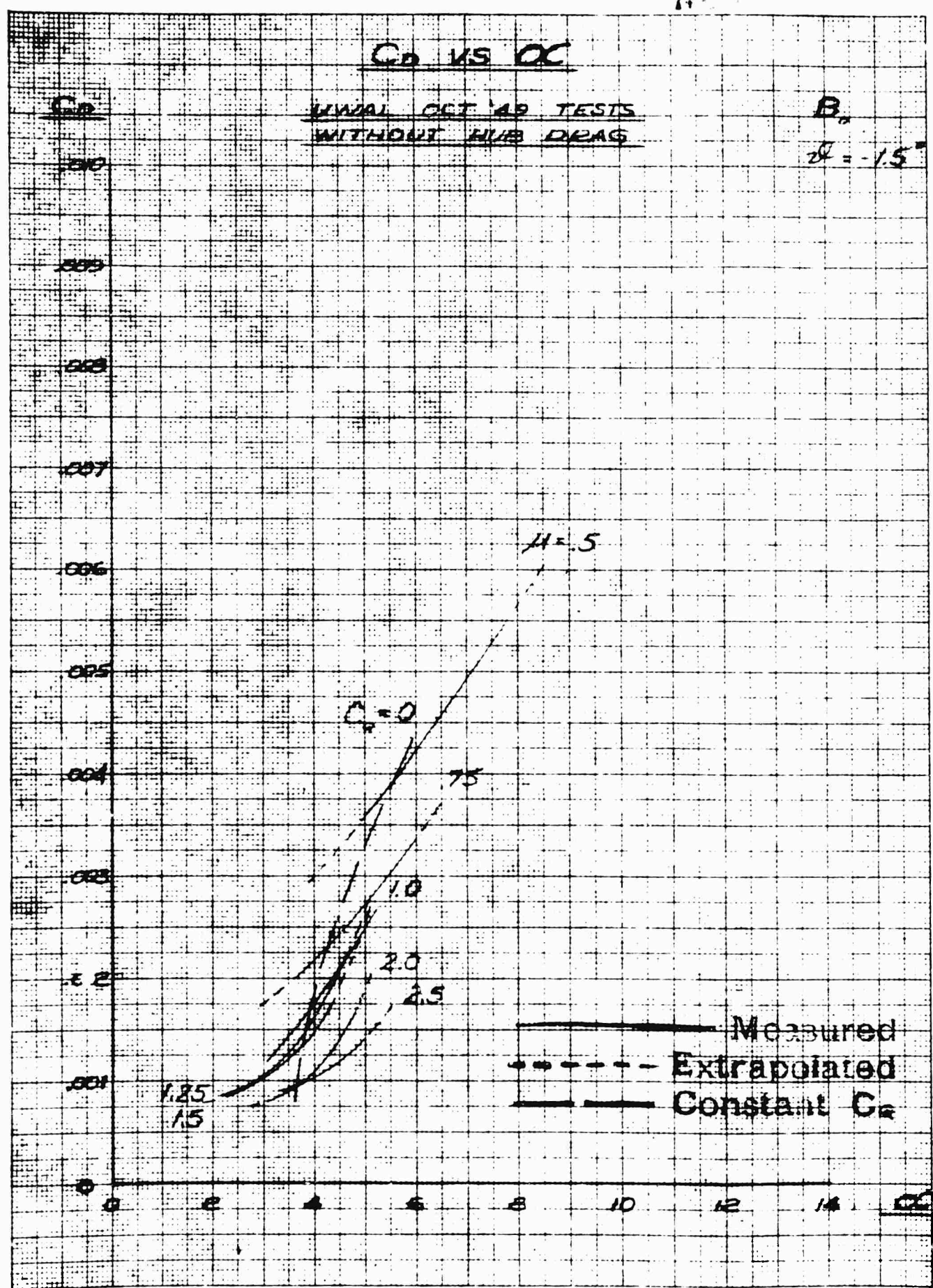
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C_D VS OC

UNVAL OCT '49 TESTS
WITHOUT HUB DRAG

B_p
 $\alpha = -1.5^\circ$



KEUFFEL & ESSER CO.

No. 359 14. Millimeters. 5 mm lines accented. cm lines heavy

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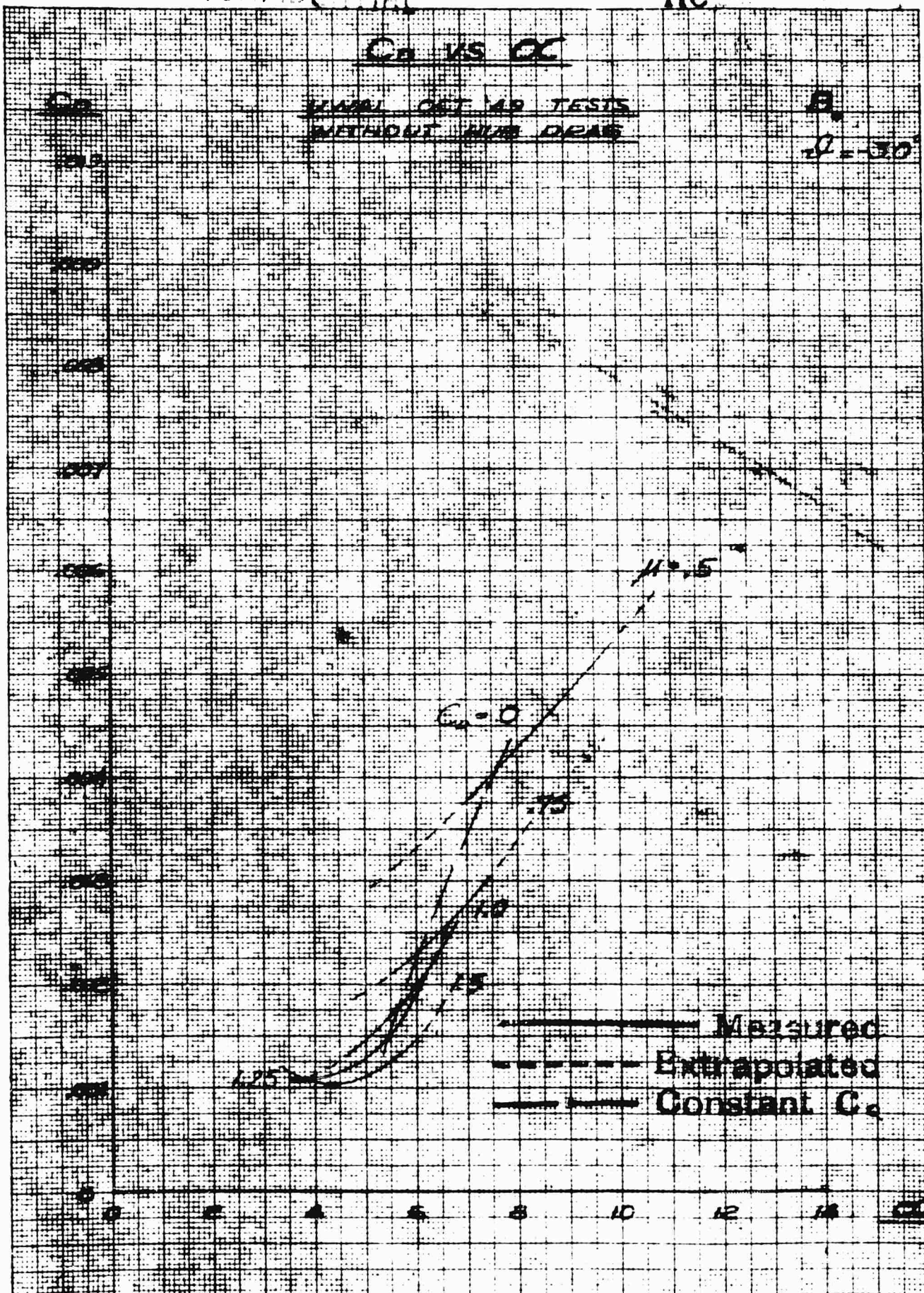
Revised

C_D VS C_L

WIND TUNNEL TESTS
WITHOUT HUB DRAG

B.

$\alpha = 30^\circ$



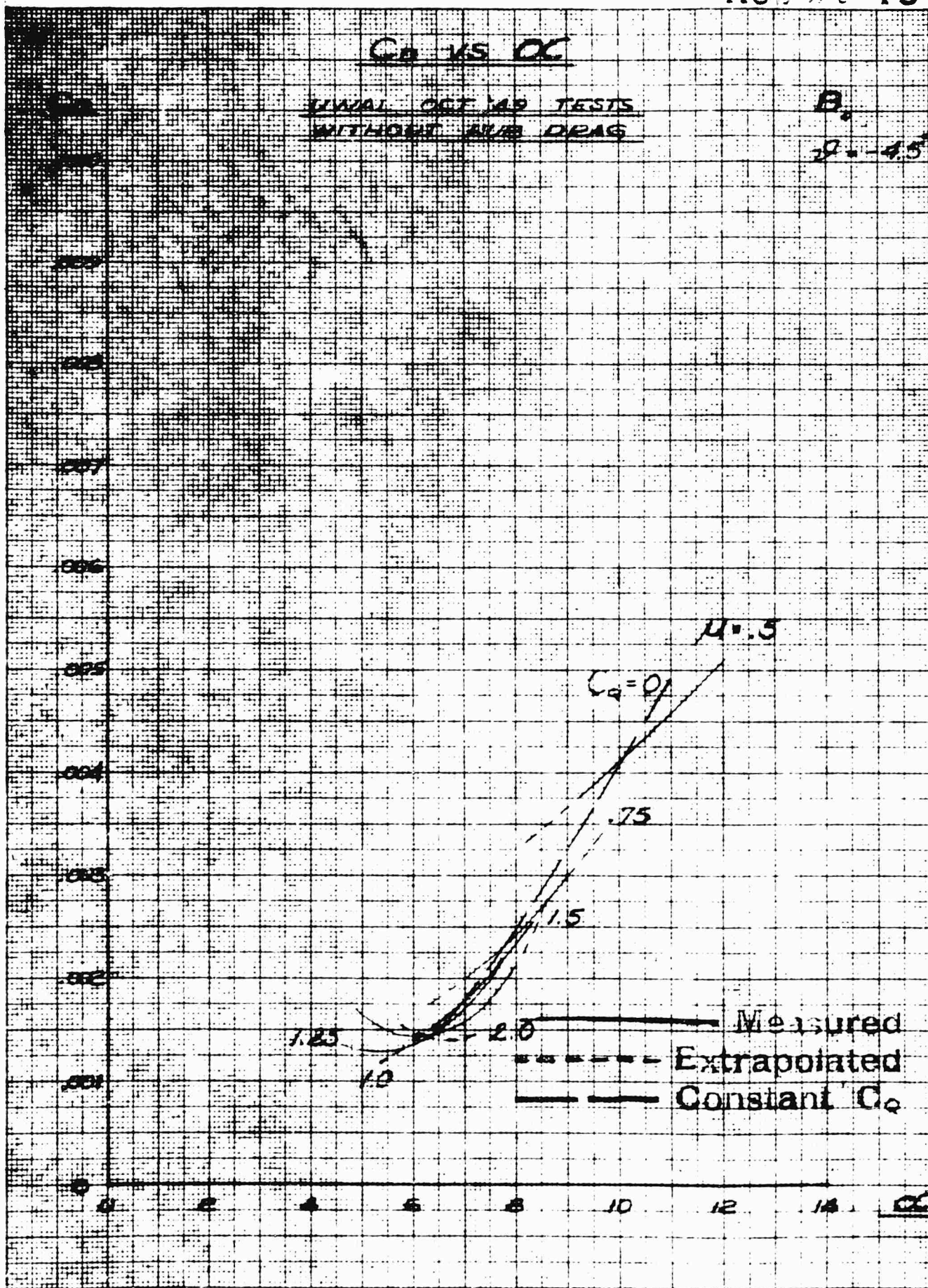
KEUFFEL & ESSER CO.

No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.
MADE IN U.S.A.

C_D VS OC

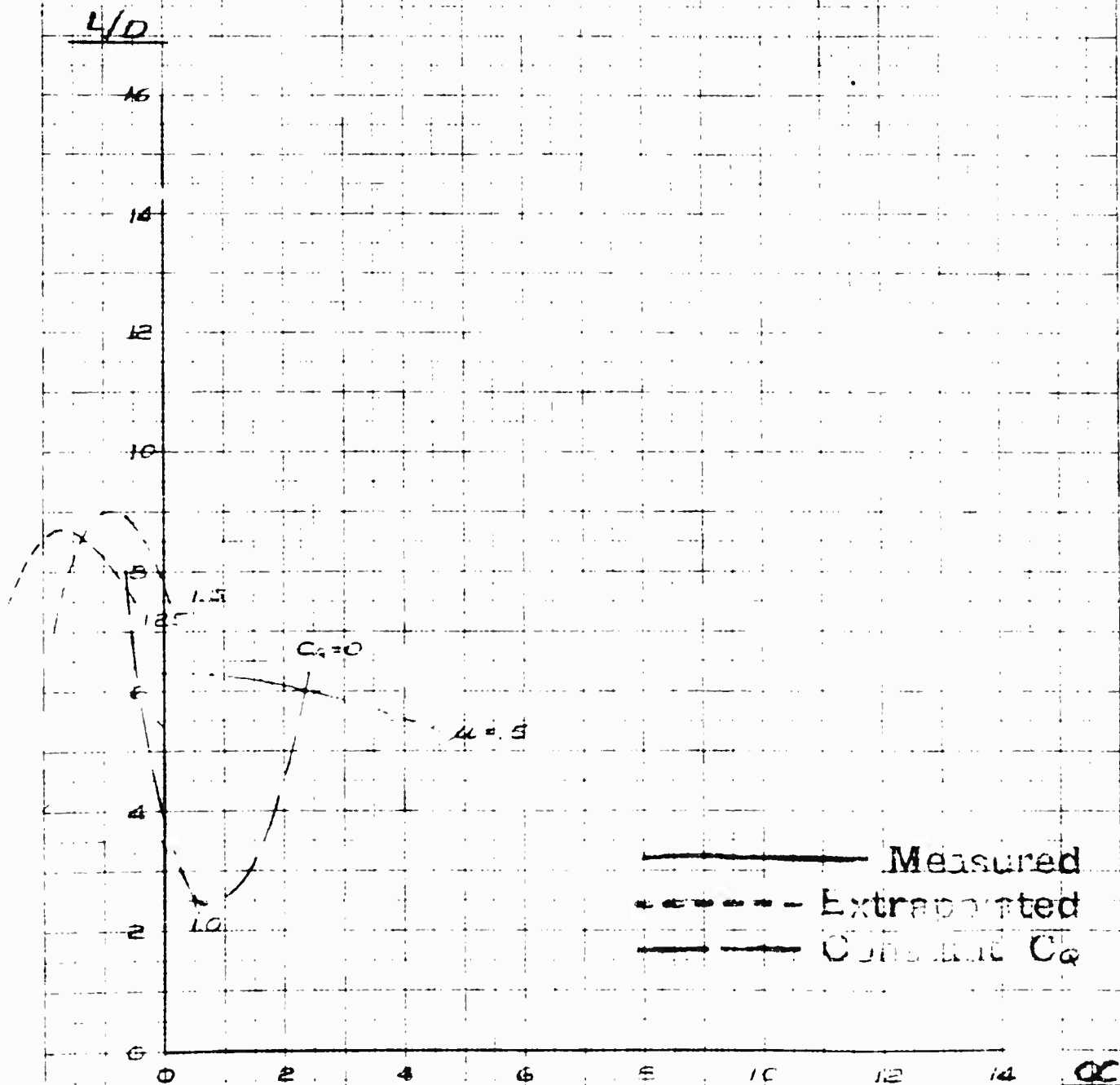
WIND TUNNEL TESTS
WITHOUT AIR DRAG

B_p
 2.45



L/D vs OC

UNVAL OCT 49 TESTS
WITHOUT HUB DRAG

 B_0
$$\varphi = +3.0$$


L/D VS OC

UNVAL OCT 49 TESTS
WITHOUT HUB DRAG

B.

$\alpha = +1.5^\circ$

L/D

16

14

12

10

8

6

4

2

0

$\mu = 2.5$

2.0

1.5

1.25

$C_d = 0$

.5

————— Measured
- - - - - Extrapolated
————— Constant C_d

0

2

4

6

8

10

12

14

OC

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105

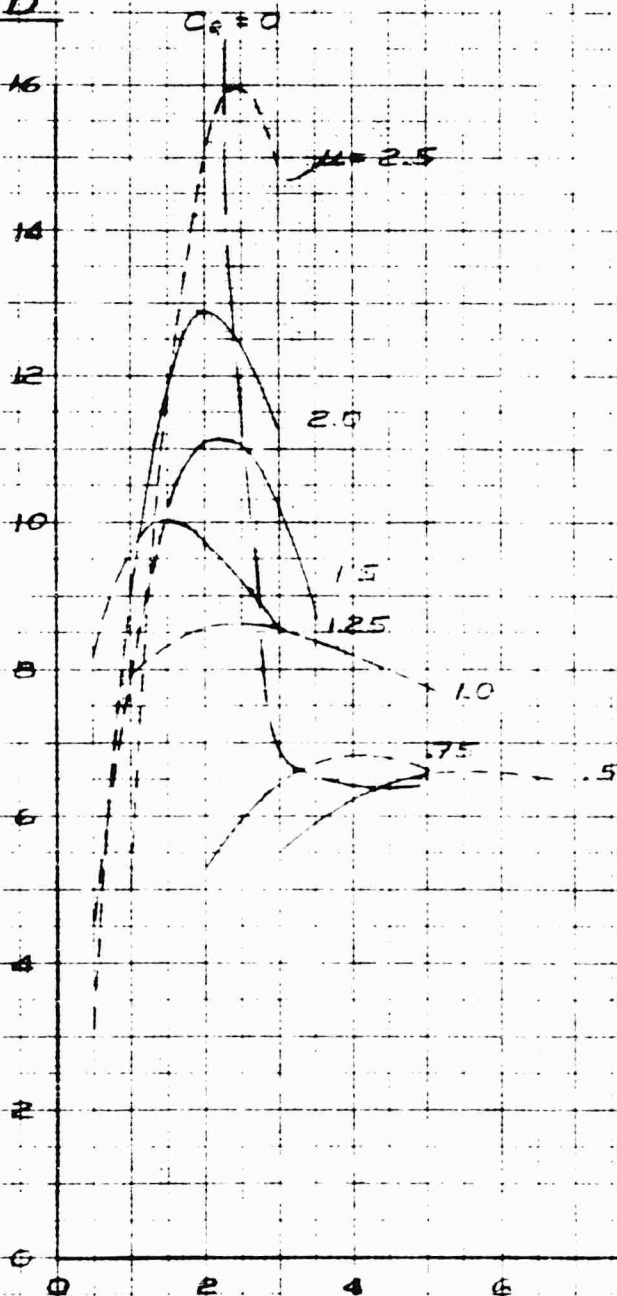
L/D VS OC

UNVAL OCT 49 TESTS
WITHOUT HUE DRAG

B_c

$\theta = 0^\circ$

L/D



— No. 100
- - - Extrapolated
— Constant C_D

L/D vs OC

UNAL. OCTAD TESTS
WITHOUT HUB DRAG

B_0

$\alpha = -1.5^\circ$

L/D

16

14

12

10

8

6

4

2

0

0

2

4

6

8

10

12

14

OC

$\mu = 2.5$

1.5 2.0

1.25

1.0

.75

.5

$C_d = 0$

Measured
Extrapolated
Constant C_d

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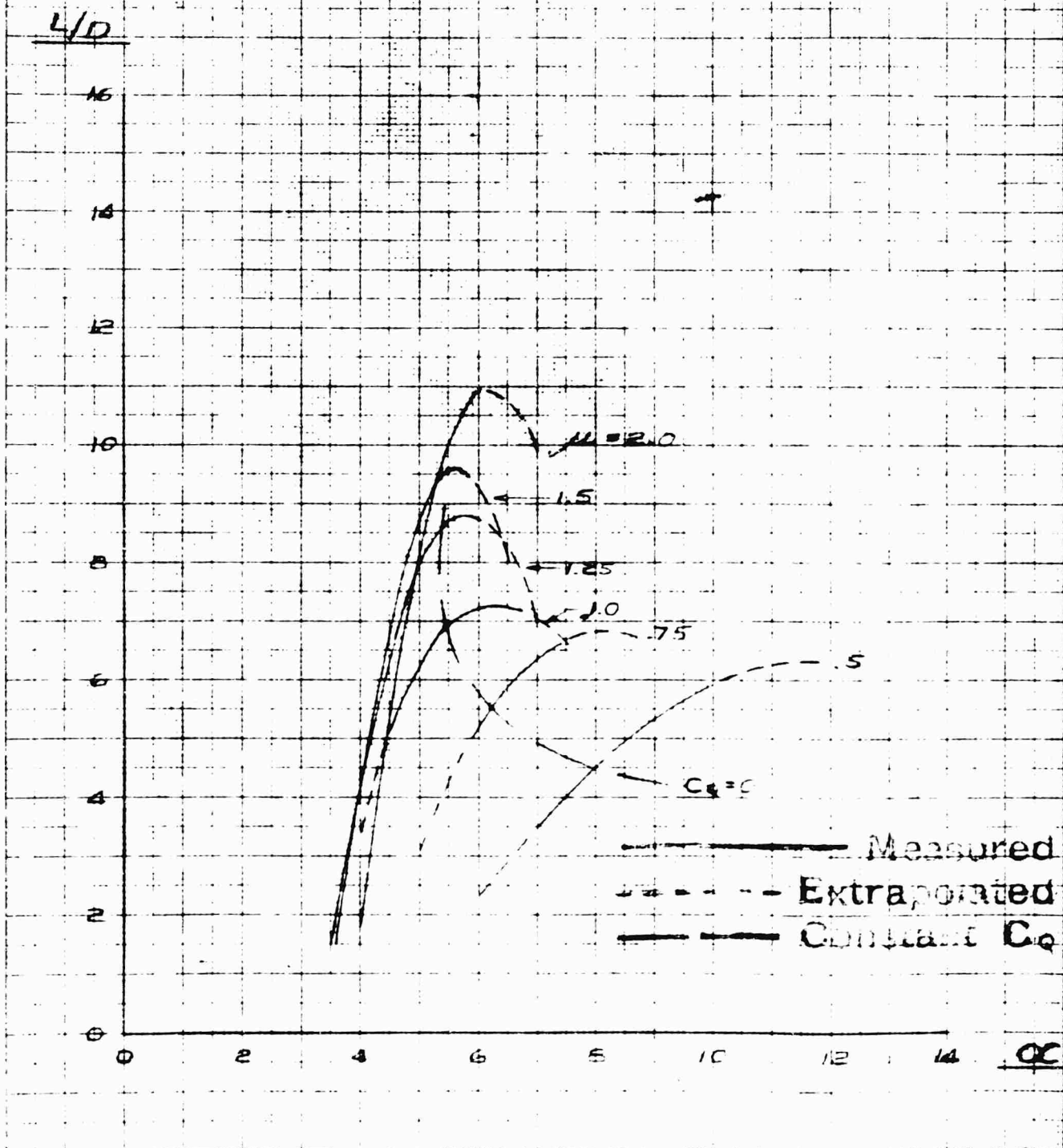
PL 87 107
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L/D VS OC

UNAL OCT 19 TESTS
WITHOUT HUB DRAG

B.

$\beta = -3.0^\circ$



KRUPPEL & ESSER CO.

3 3 13 8 minutes 5 min lines started on line 100

L/D vs OC

UNAL OCTAD TESTS
WITHOUT HUB DRAG

B_0

$\theta = -4.5^\circ$

L/D

16

14

12

10

8

6

4

2

0

2

4

6

8

10

12

14

OC

$\mu = 2.0$

$\mu = 1.5$

$\mu = 1.25$

$\mu = 1.0$

$\mu = .75$

$\mu = .5$

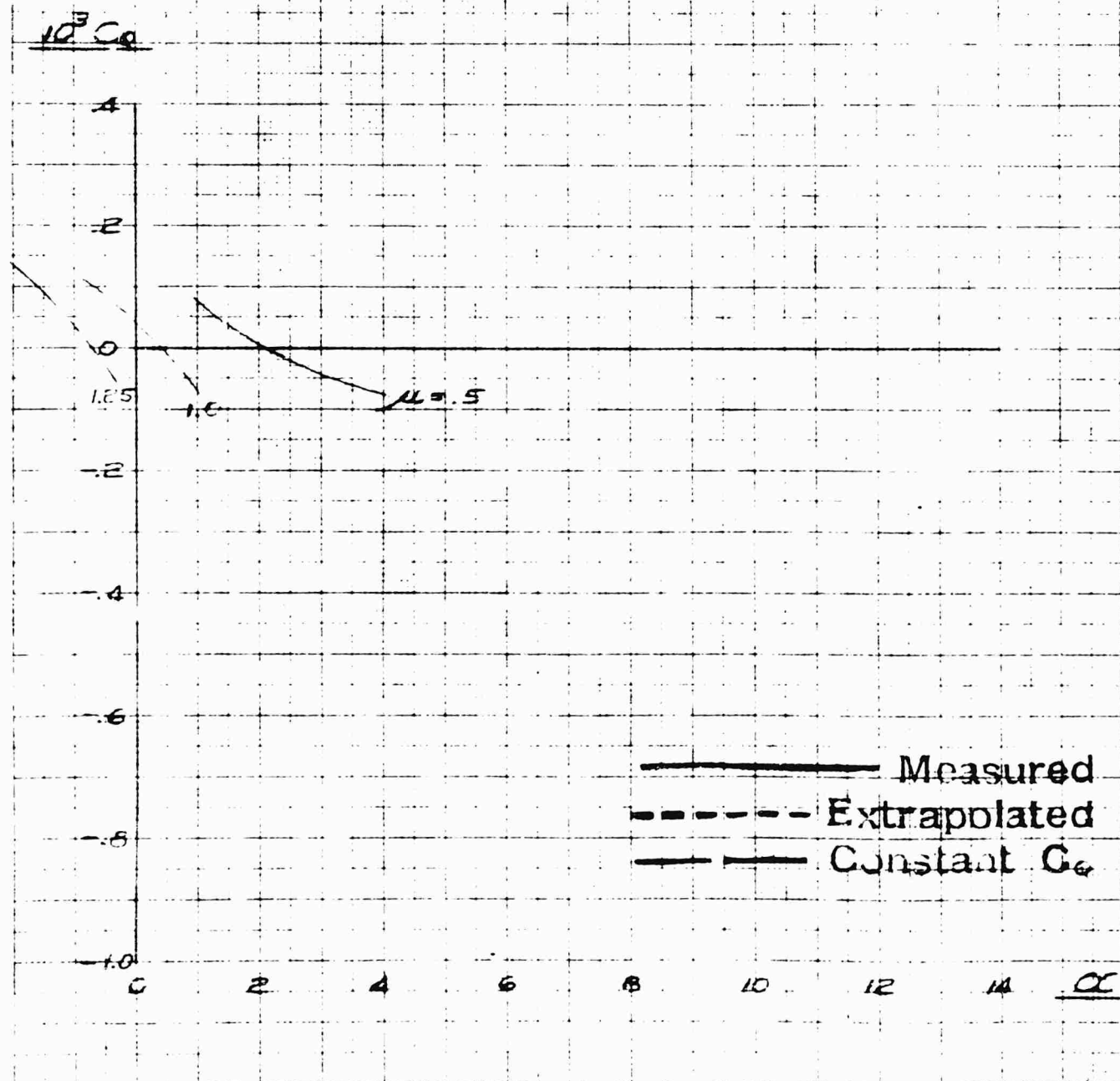
$C_q = 0$

Measured
Extrapolated
Constant C_q

C_Q VS α

UNAL CLT '42 TESTS
WITHOUT HUB DBAG

B_0
 $\delta = +3.0^\circ$



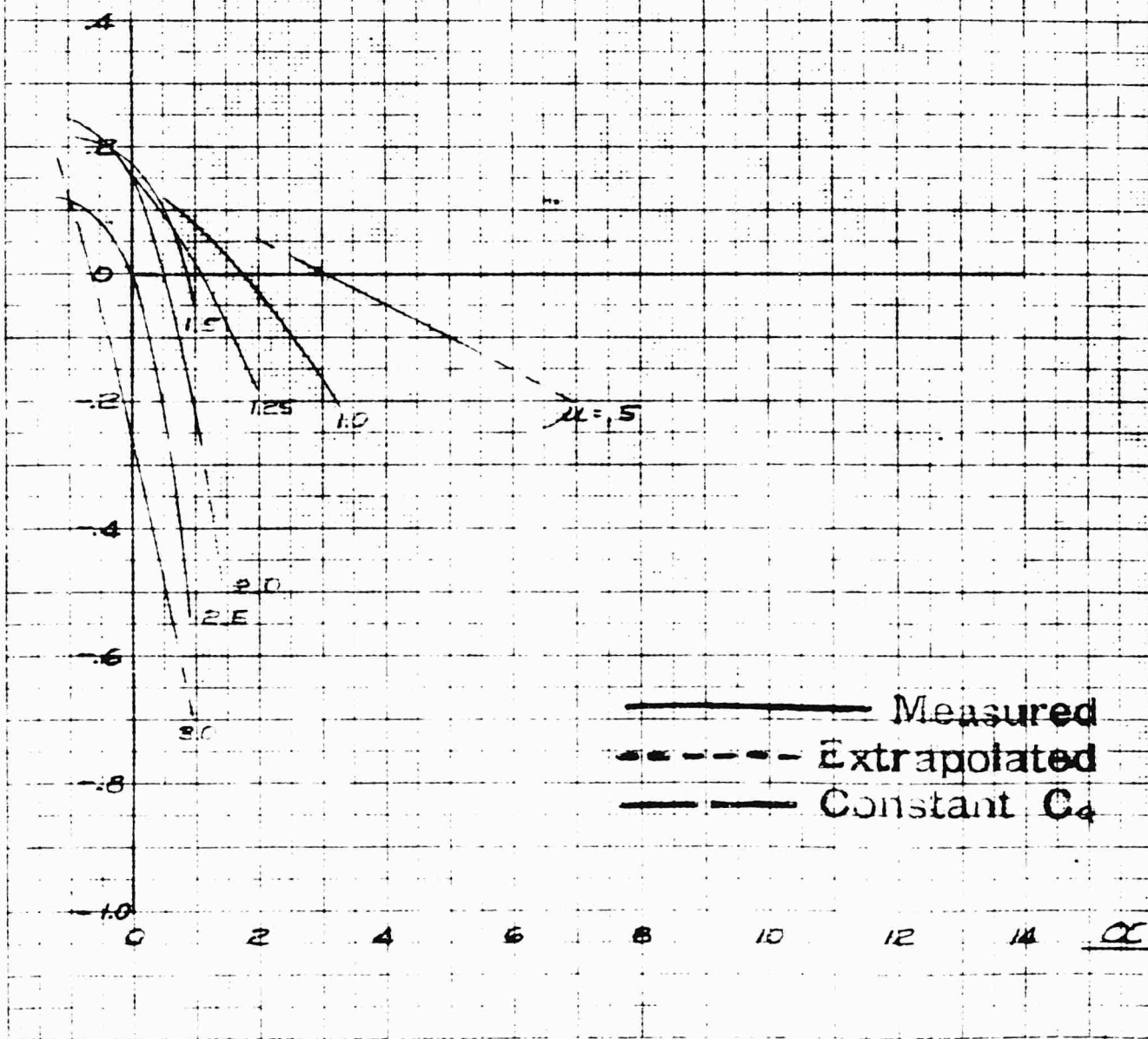
C_Q vs α

UNVAL OCT '49 TESTS
WITHOUT HUB DRAG

B_0

$\beta = +15^\circ$

$10^3 C_Q$



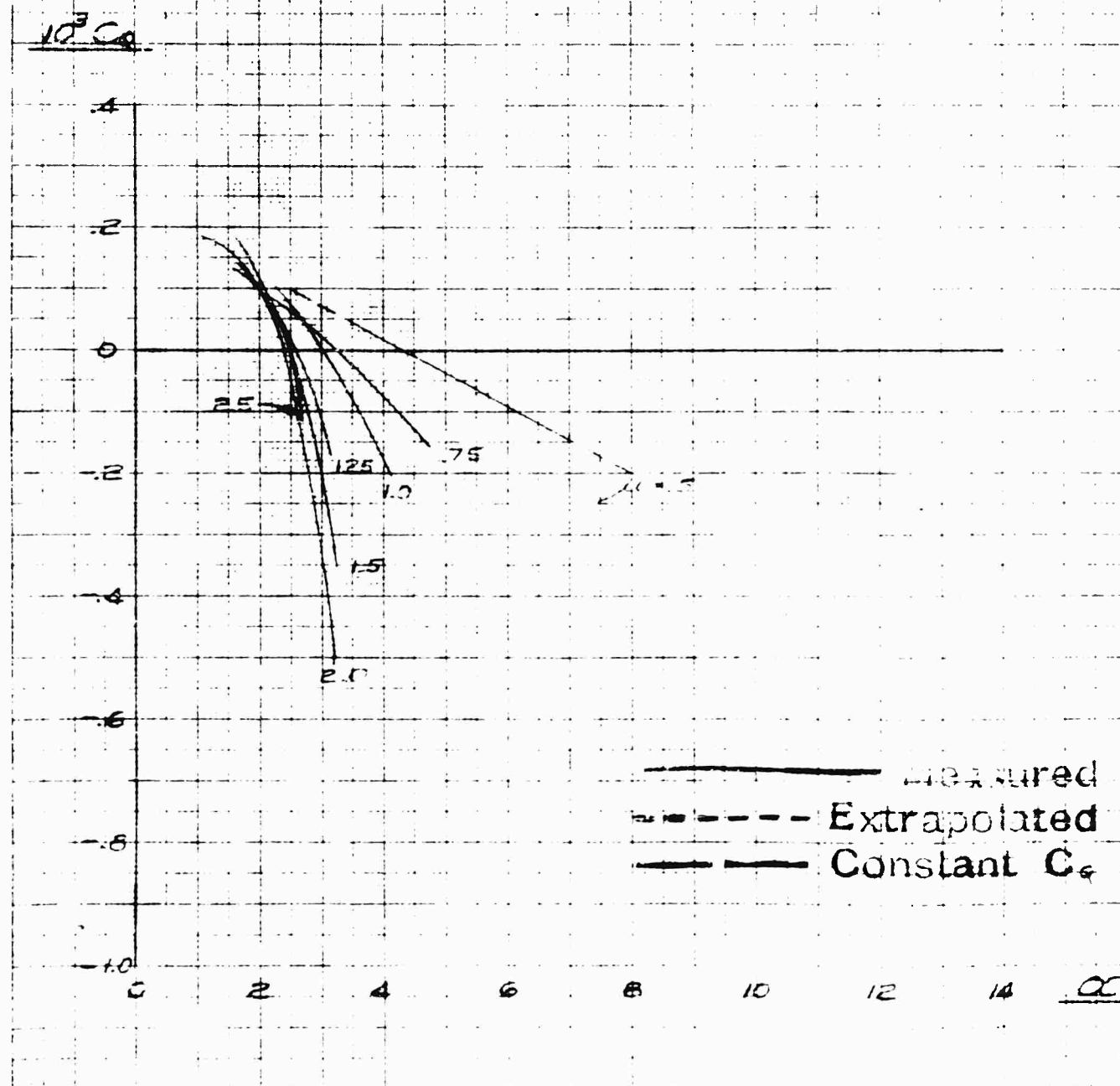
— Measured
- - - Extrapolated
— Constant C_Q

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C_e VS α

UNVAL OCT '49 TESTS
WITHOUT HUB DRAG

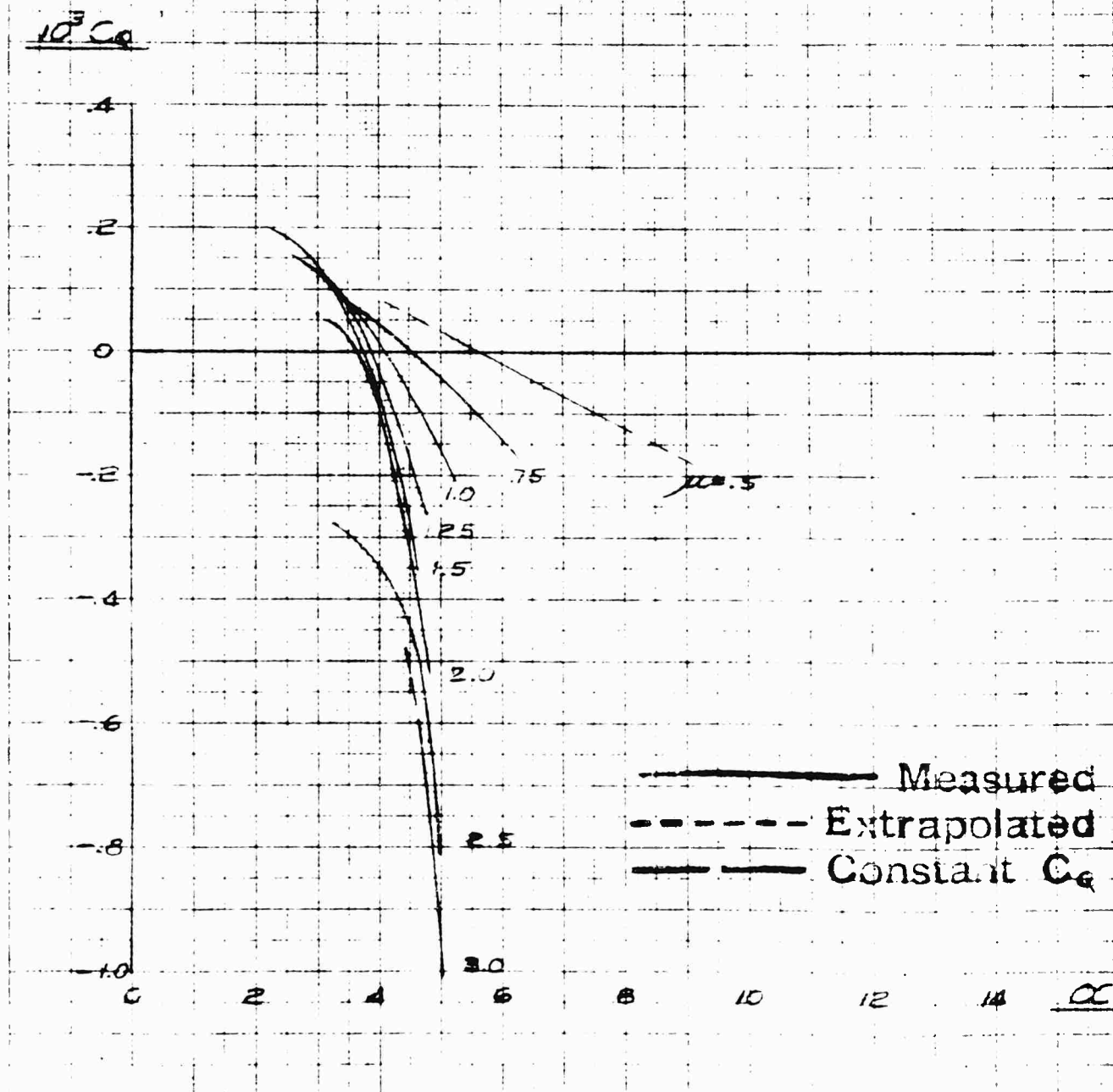
B_0
 $\theta = 0^\circ$



C_D VS α

WIND TUNNEL TESTS
WITHOUT HUB DRAG

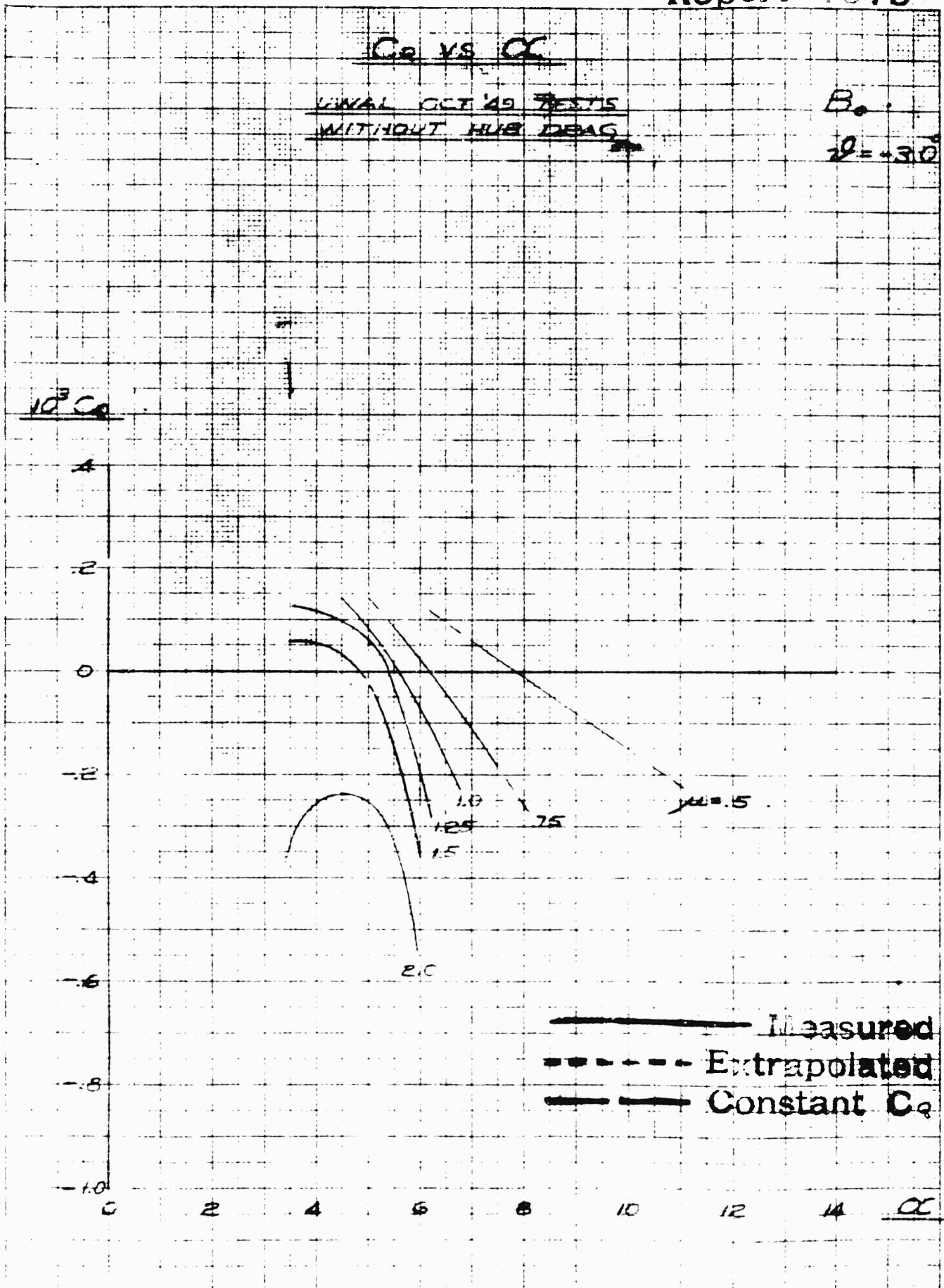
B_0
 $\alpha = +15^\circ$



C_D VS α

FINAL OCT '49 TESTS
WITHOUT HUB DRAG

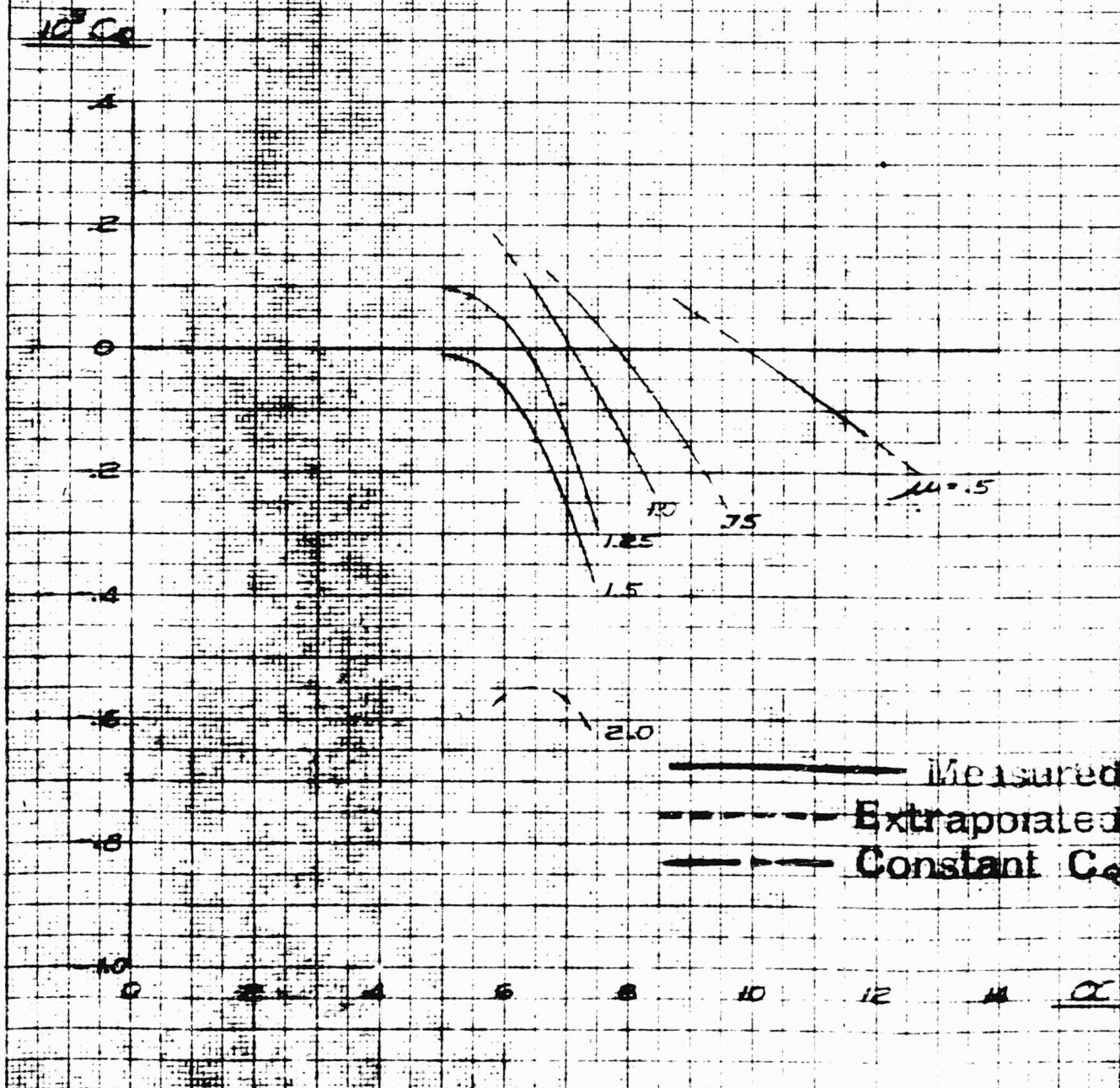
B_0
 $\beta = +30^\circ$



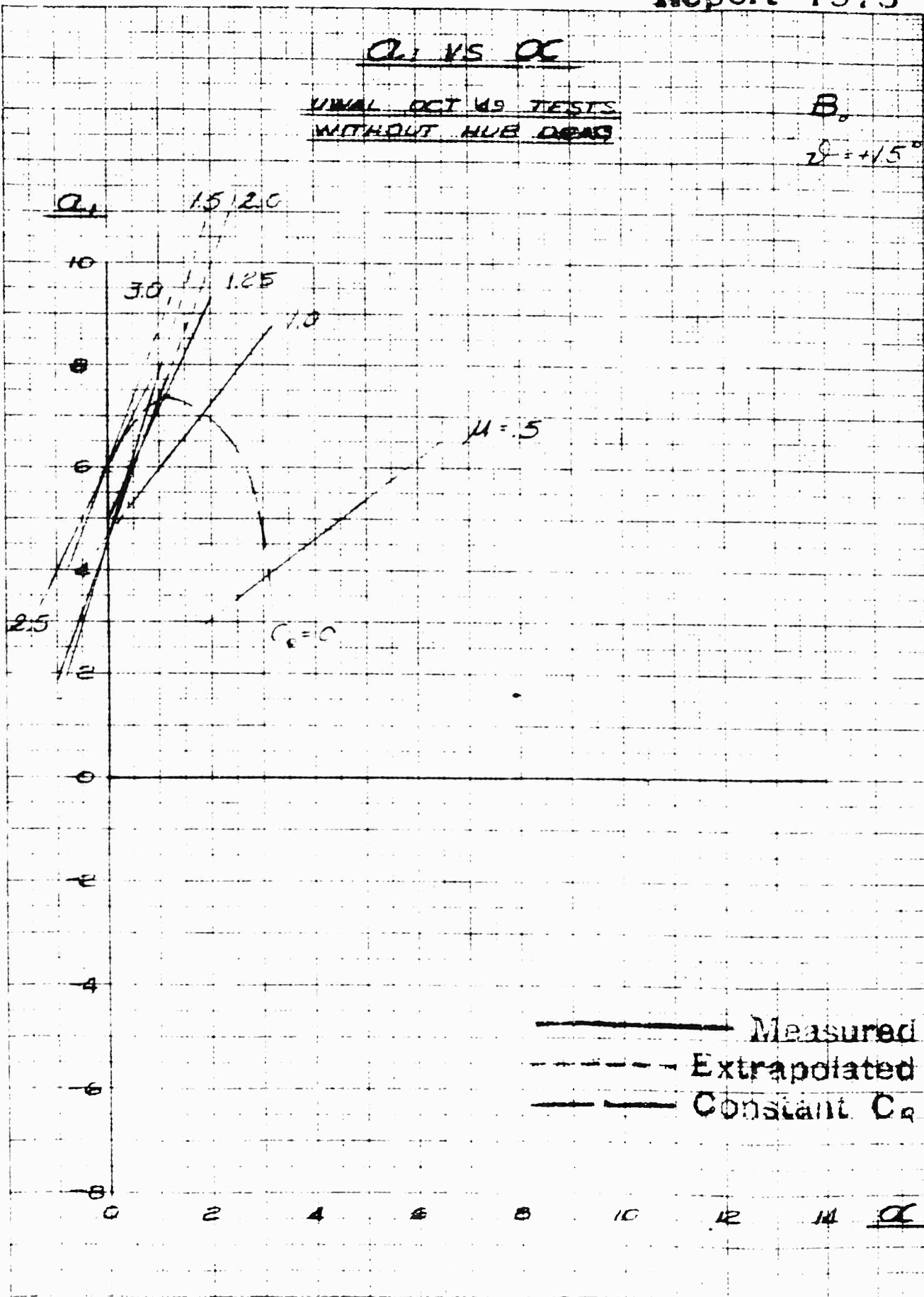
C_D VS α

WIND TUNNEL TESTS
WITHOUT HUB DRAG

B_0
 $\alpha = -4.5^\circ$





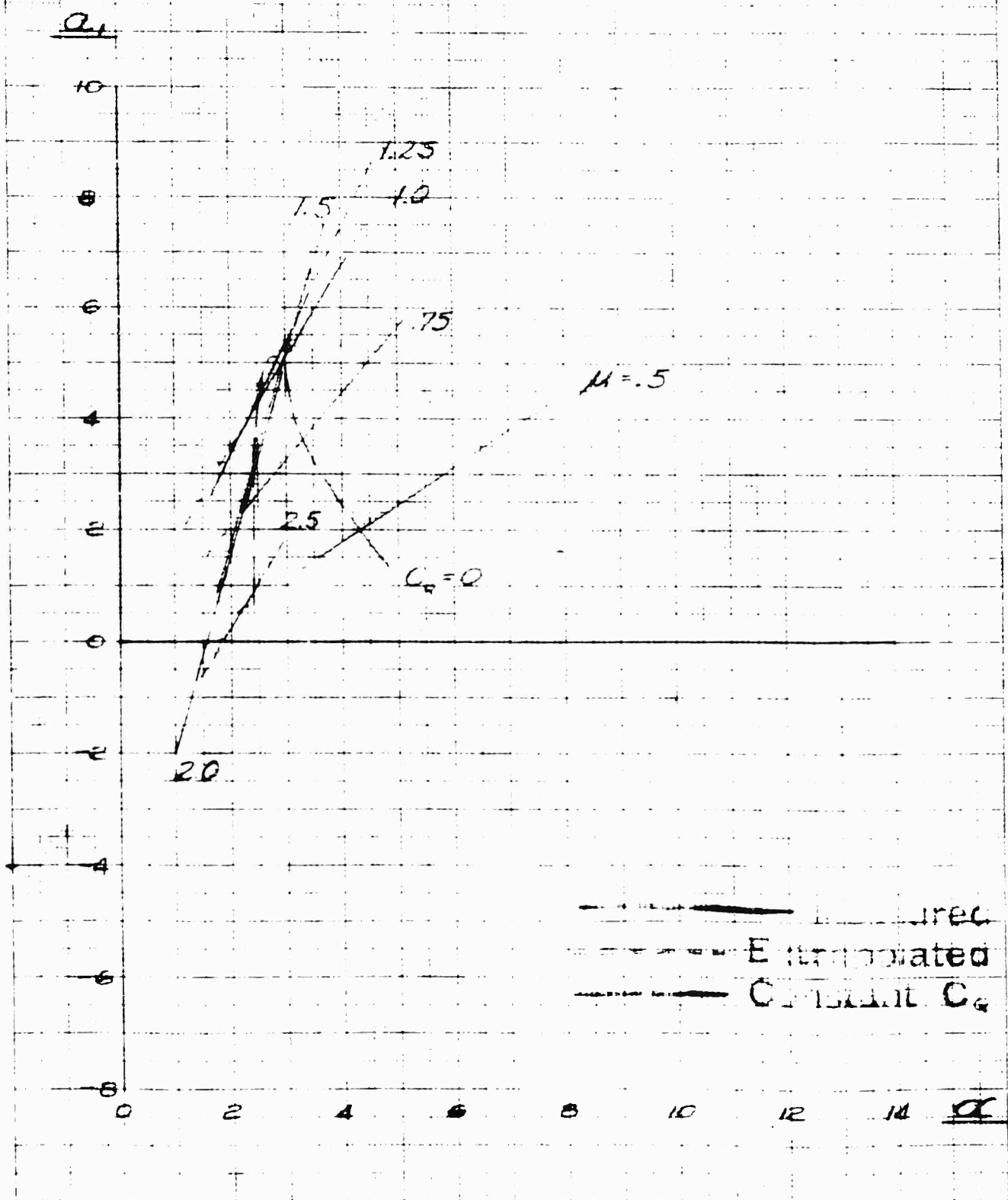


Q_1 VS α

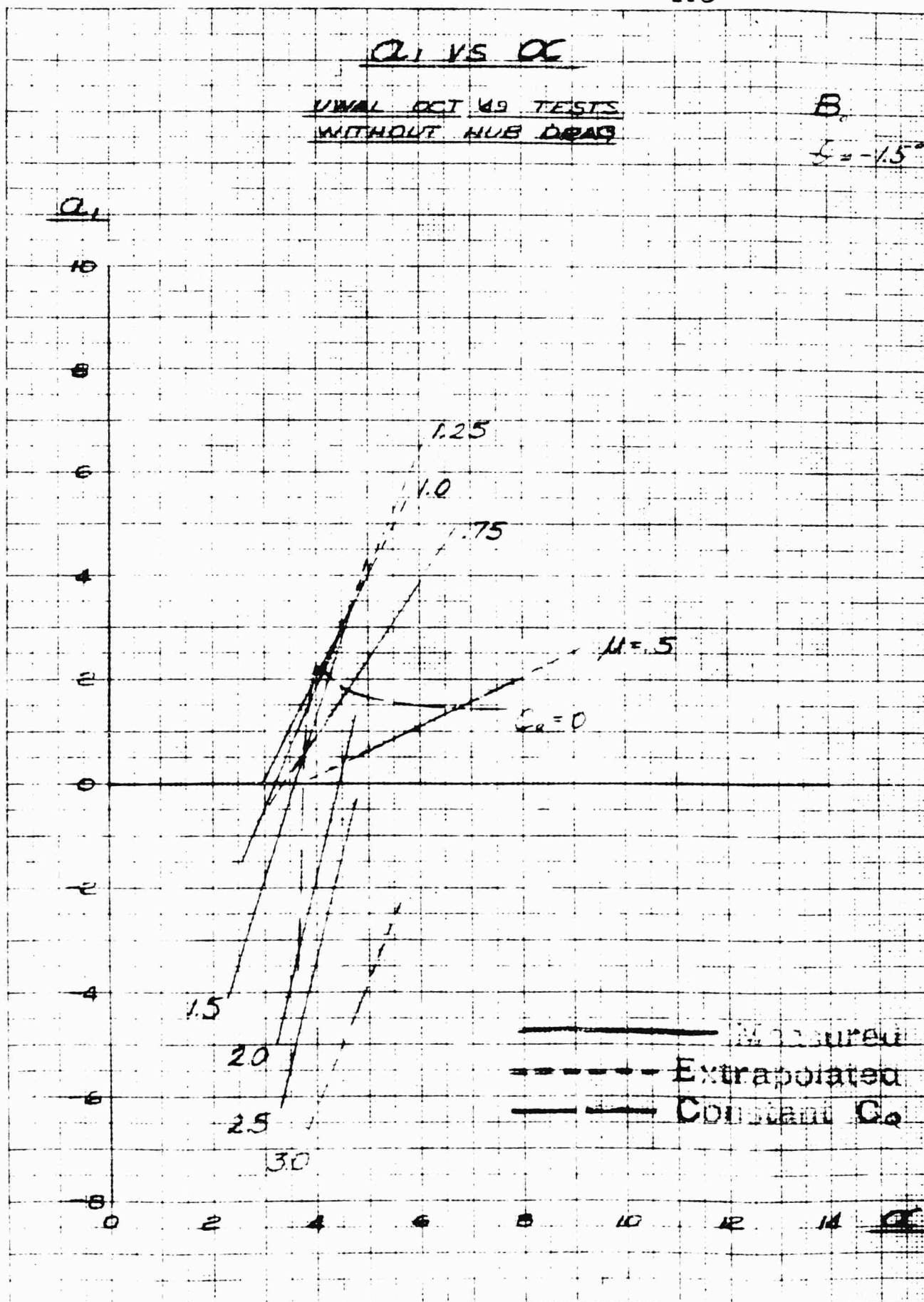
UWAL OCT 49 TESTS
WITHOUT HUB DEAD

B_c

$\lambda = 0^\circ$



— Measured
- - - Extrapolated
- · - Constant C_g



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Q_1 VS Q_2

UNVAL DET 49 TESTS
WITHOUT HUB DRAG

B_c

$D = -30^\circ$

Q_1

10

8

6

4

2

0

-2

-4

-6

-8

0

2

4

6

8

10

12

14

Q_2

1.0

.75

1.25

$H = .5$

.45

$C_c = 0$

2.0

Me

Extrapolated

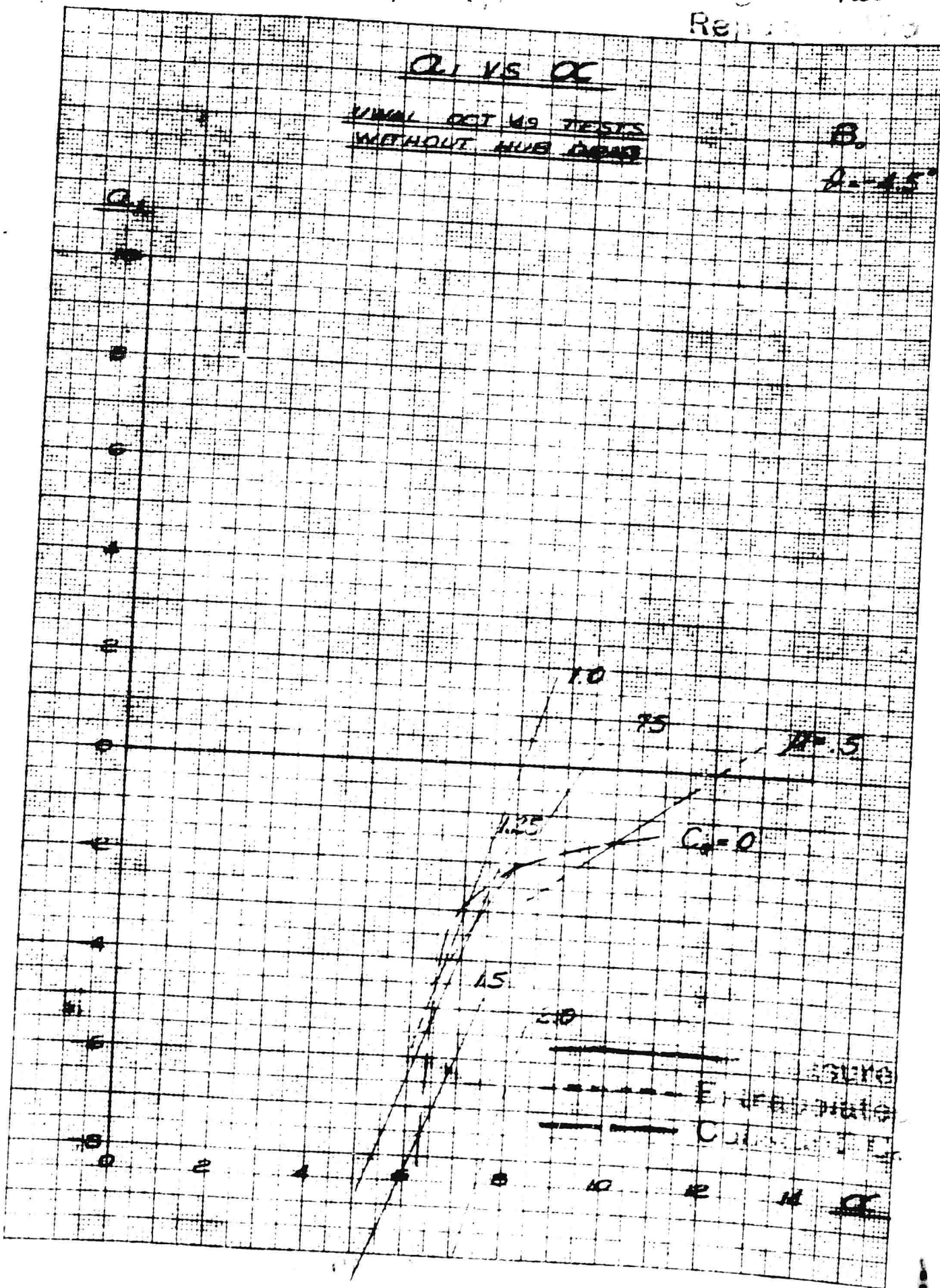
Constant C_c

Q_1 VS Q_2

WIND TUNNEL TESTS
WITHOUT HUB DRAG

B.

$\alpha = 4.5^\circ$

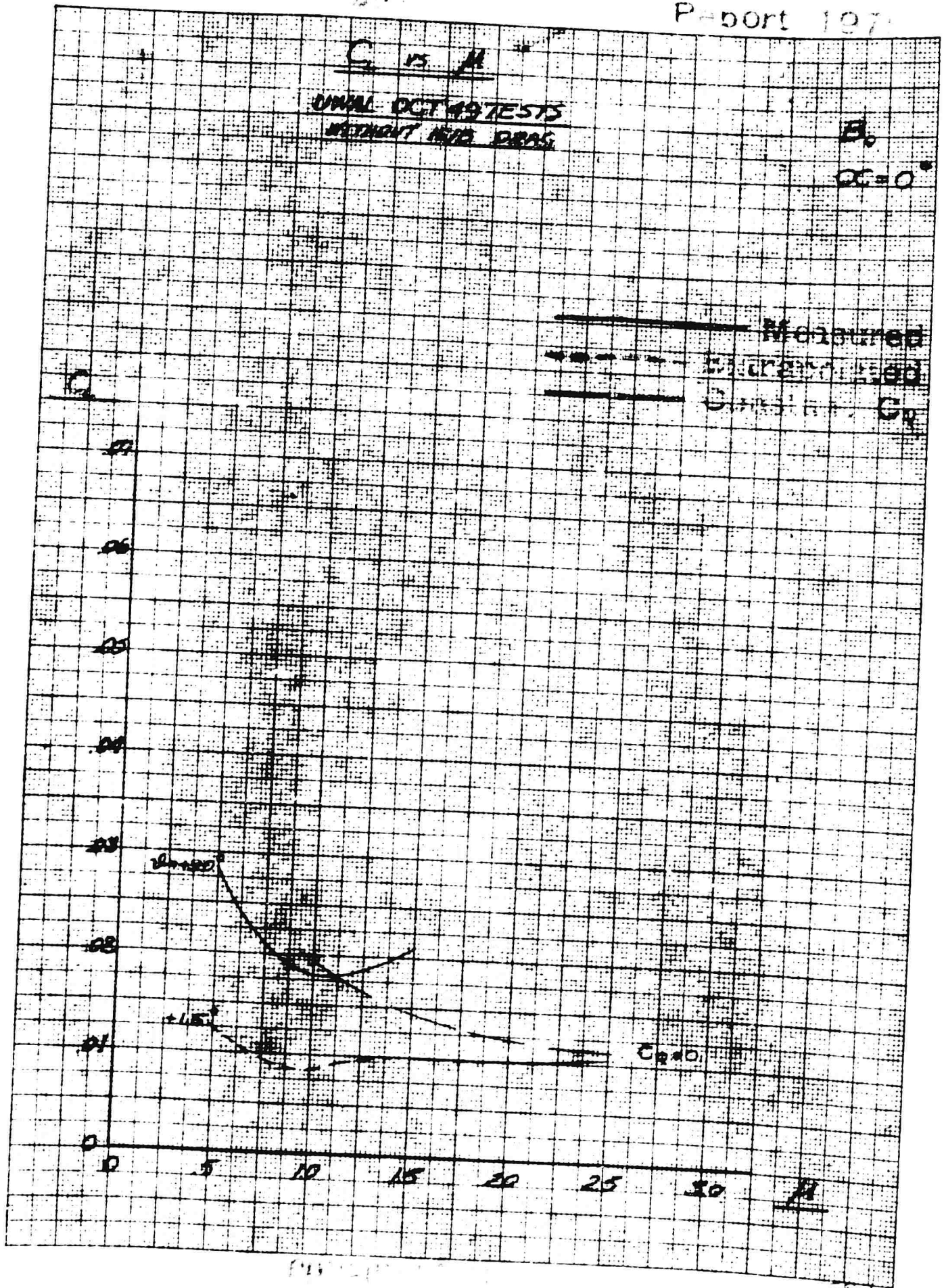


C. 15. H.

UNVAL OCT 19 TESTS
WITHOUT MID DRAG

B.
 $\alpha = 0^\circ$

Measured
Calculated
C_g



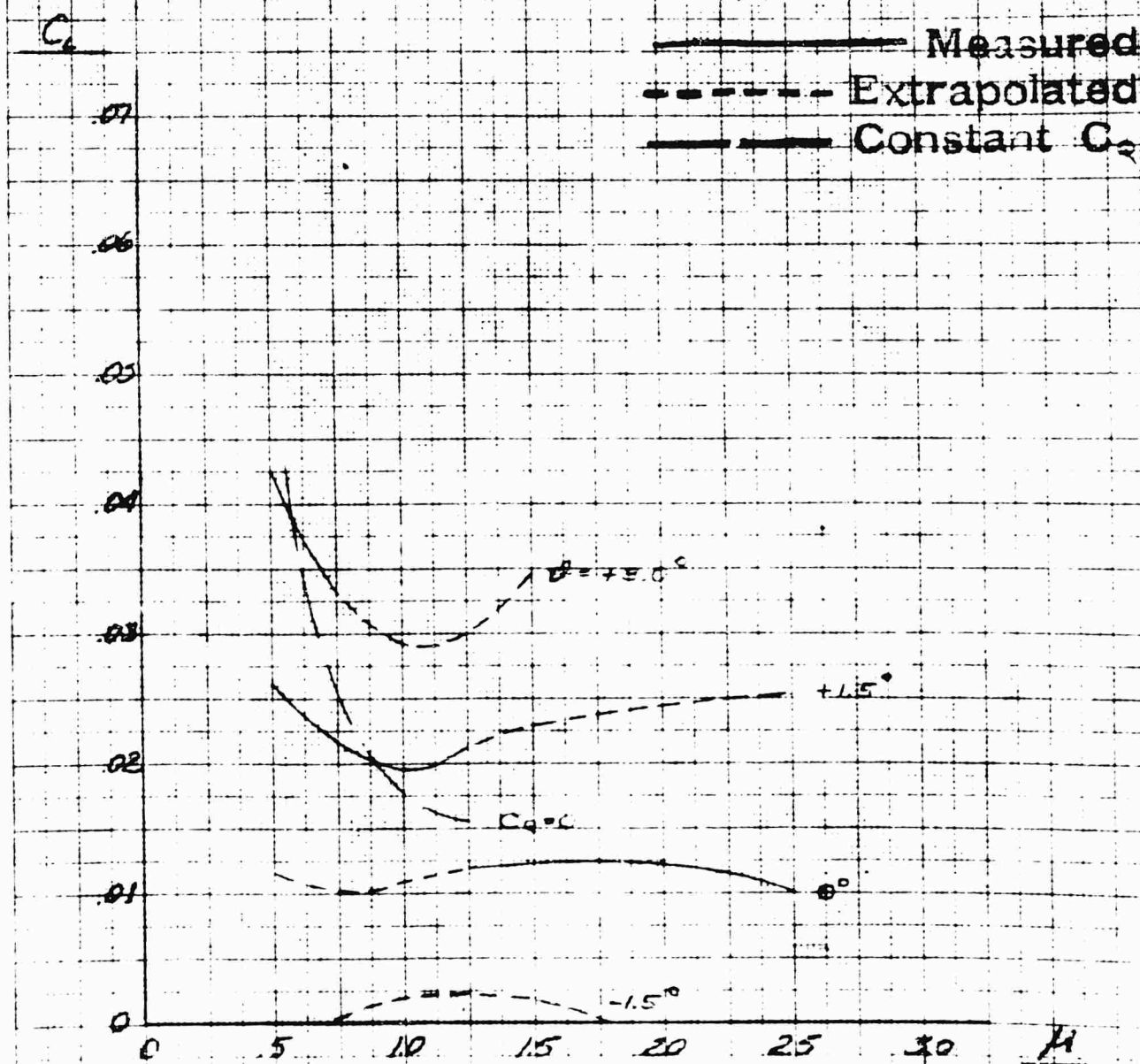
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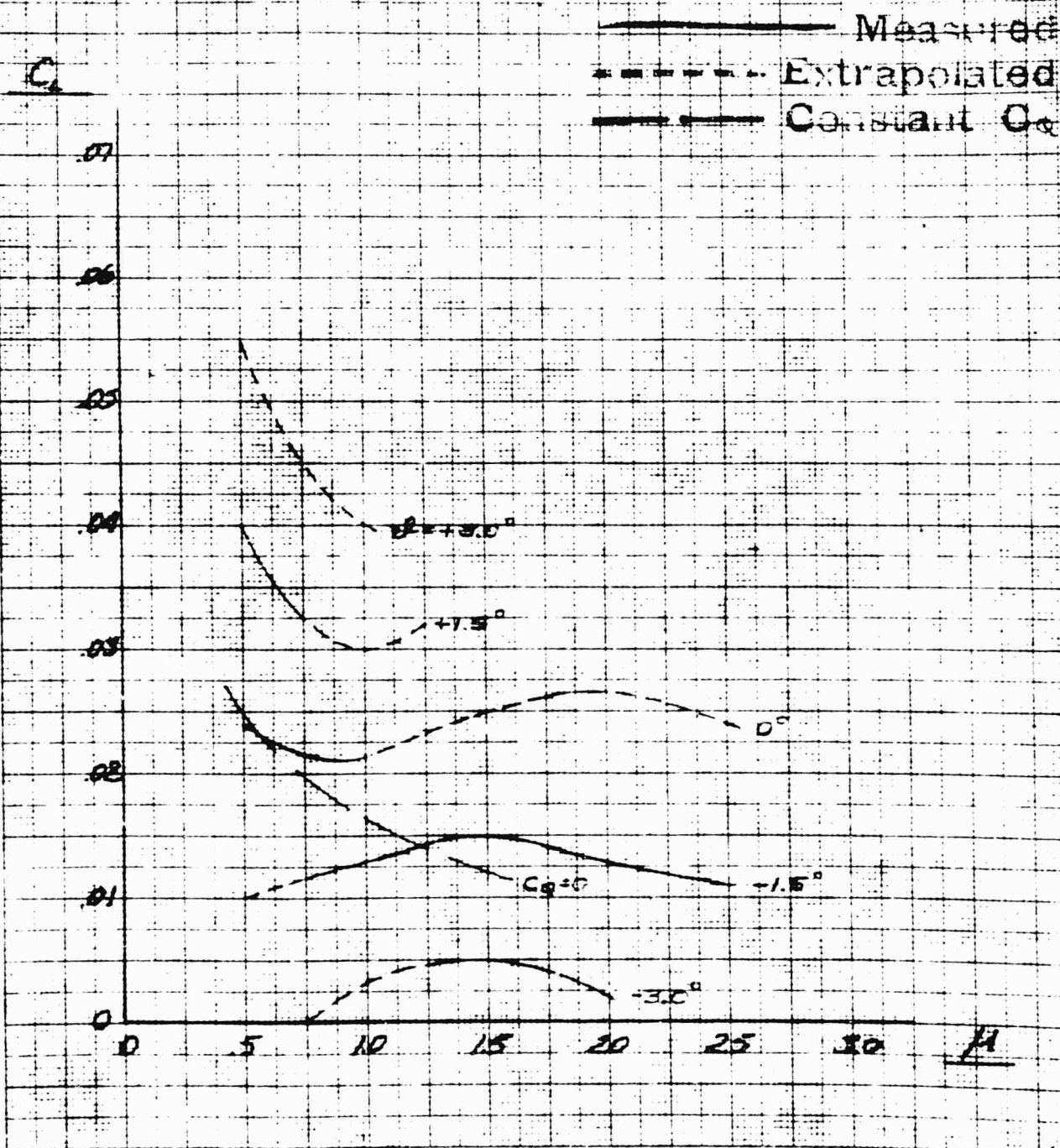
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C_L vs M

UNVAL OCT 49 TESTS
WITHOUT NUB DRAG

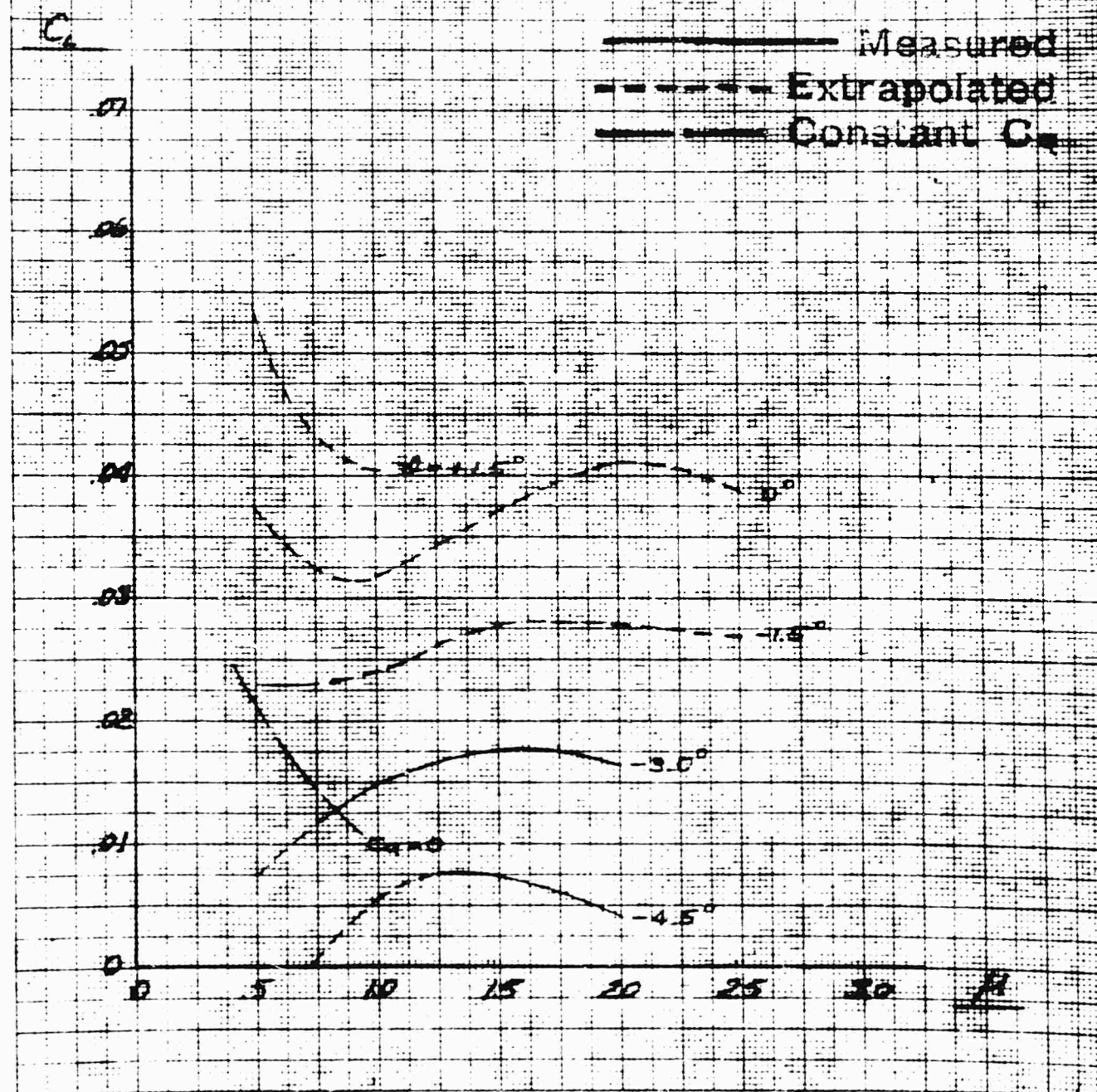
B_0
 $\alpha = 2^\circ$



C_L vs μ UNAL OCT 49 TESTS
WITHOUT HUD DRAG B_0 $\alpha = 4^\circ$ 

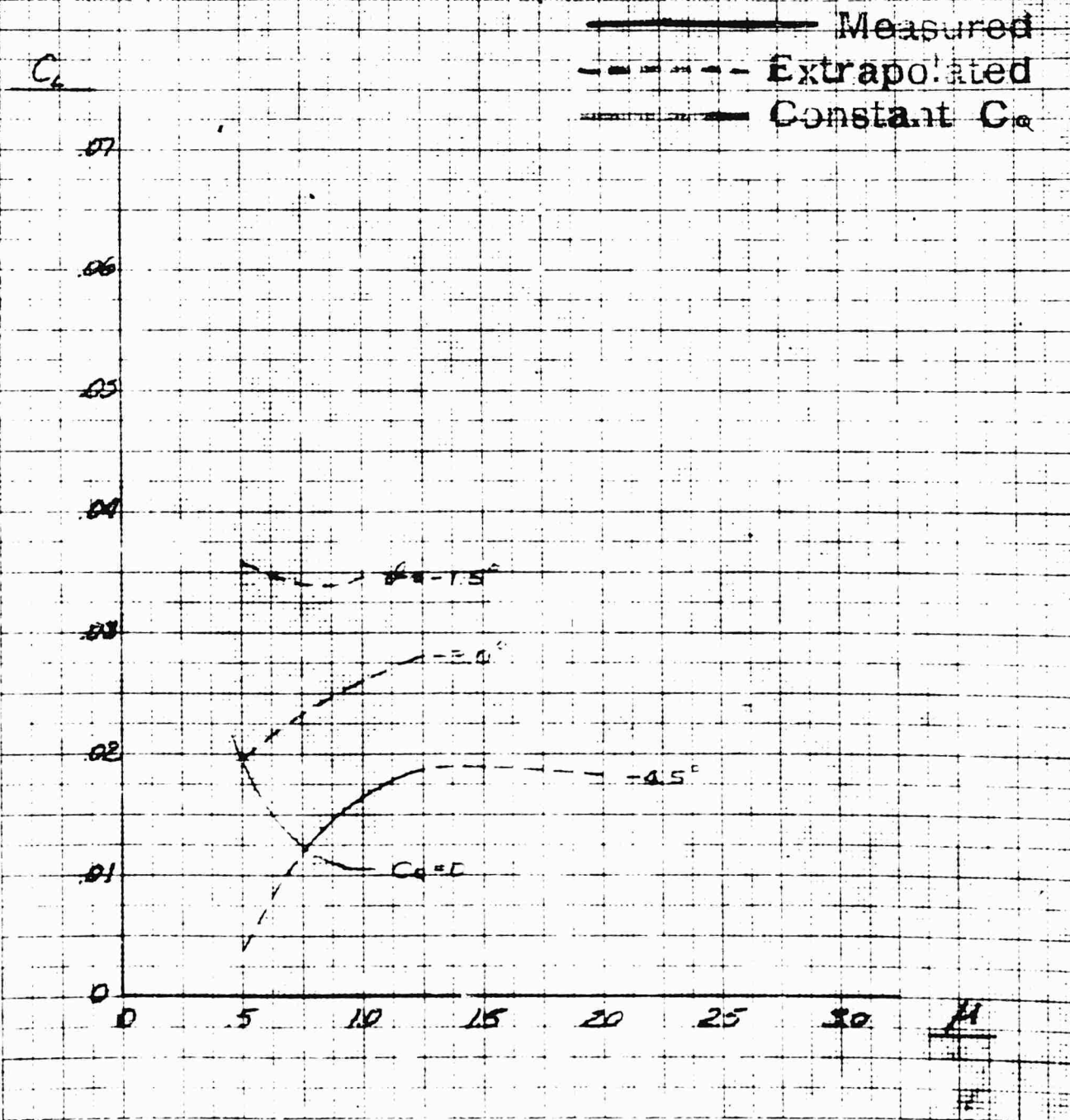
C_L vs M
UNAL OCT 49 TESTS
WITHOUT HUB DRAG

B_0
 $\alpha = 0^\circ$



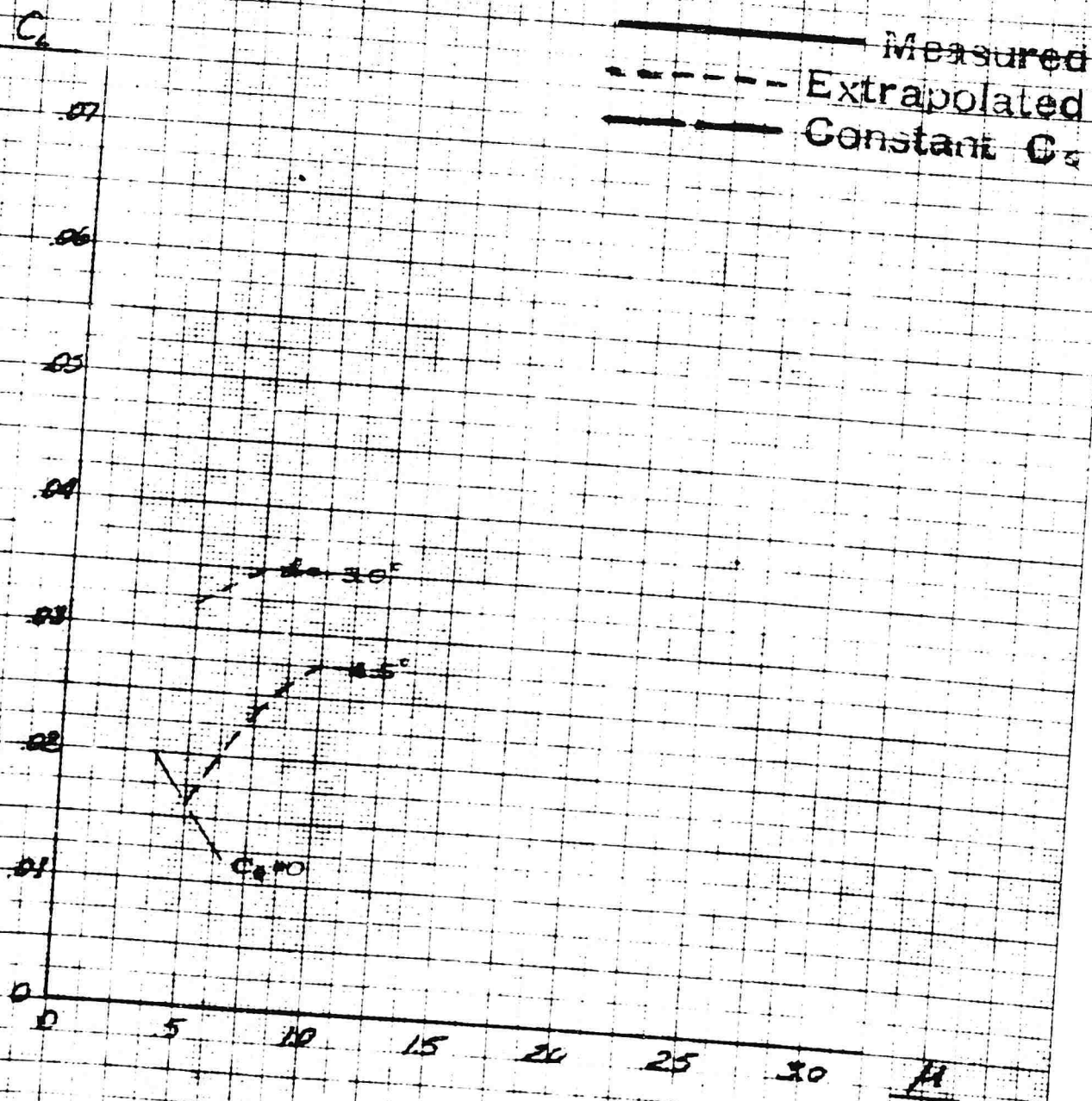
C_L vs M
UNVAL OCT 49 TESTS
WITHOUT HUD DRAG

B_0
 $\alpha = 8^\circ$



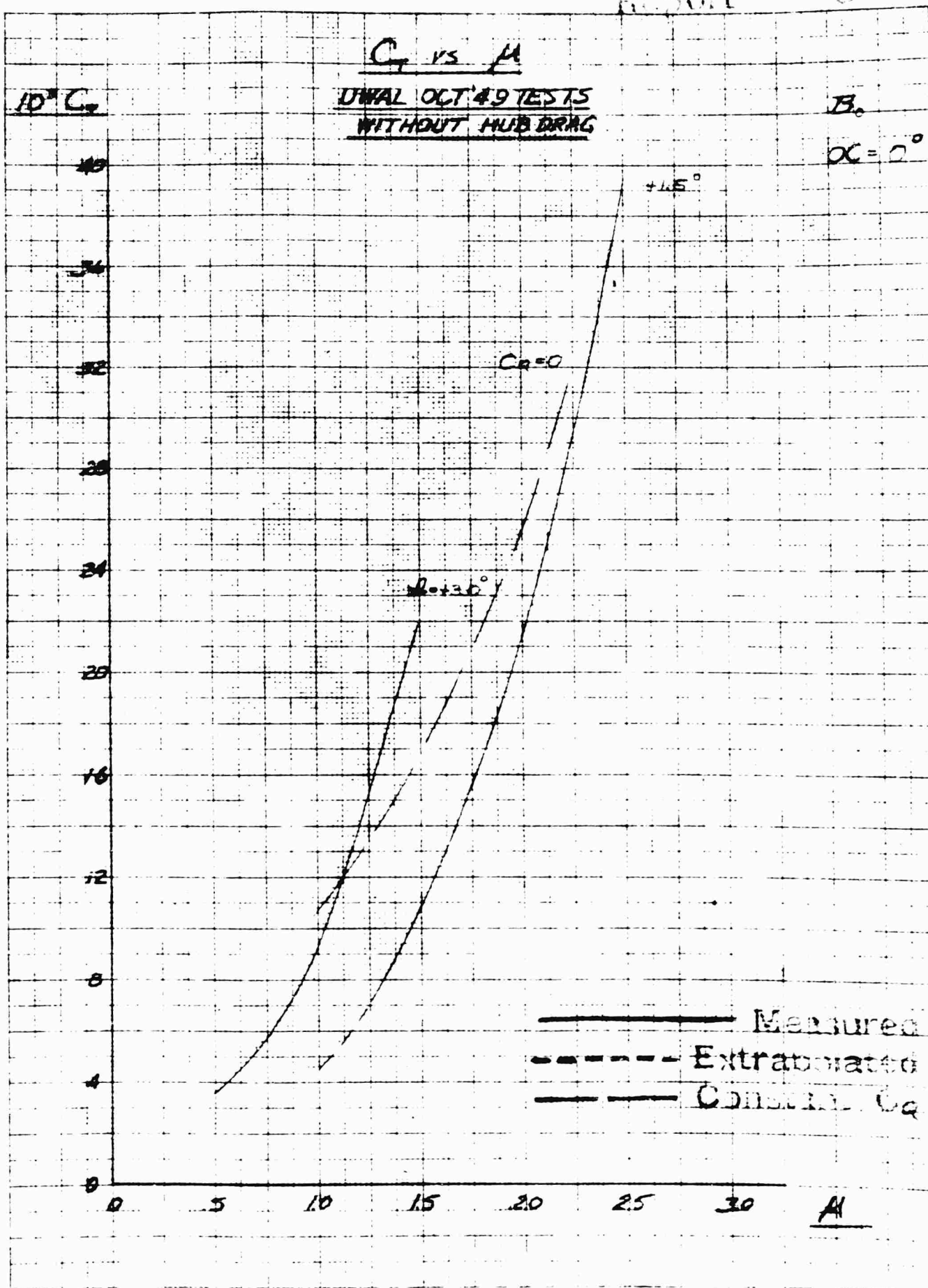
C_L vs μ
UNIAL OCT 49 TESTS
WITHOUT MUD DRAG

B_0
 $OC=10^\circ$



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Report

 C_T vs M UWAL OCT '49 TESTS
WITHOUT HUB DRAG B_0 $\alpha = 0^\circ$ $10^3 C_T$ 

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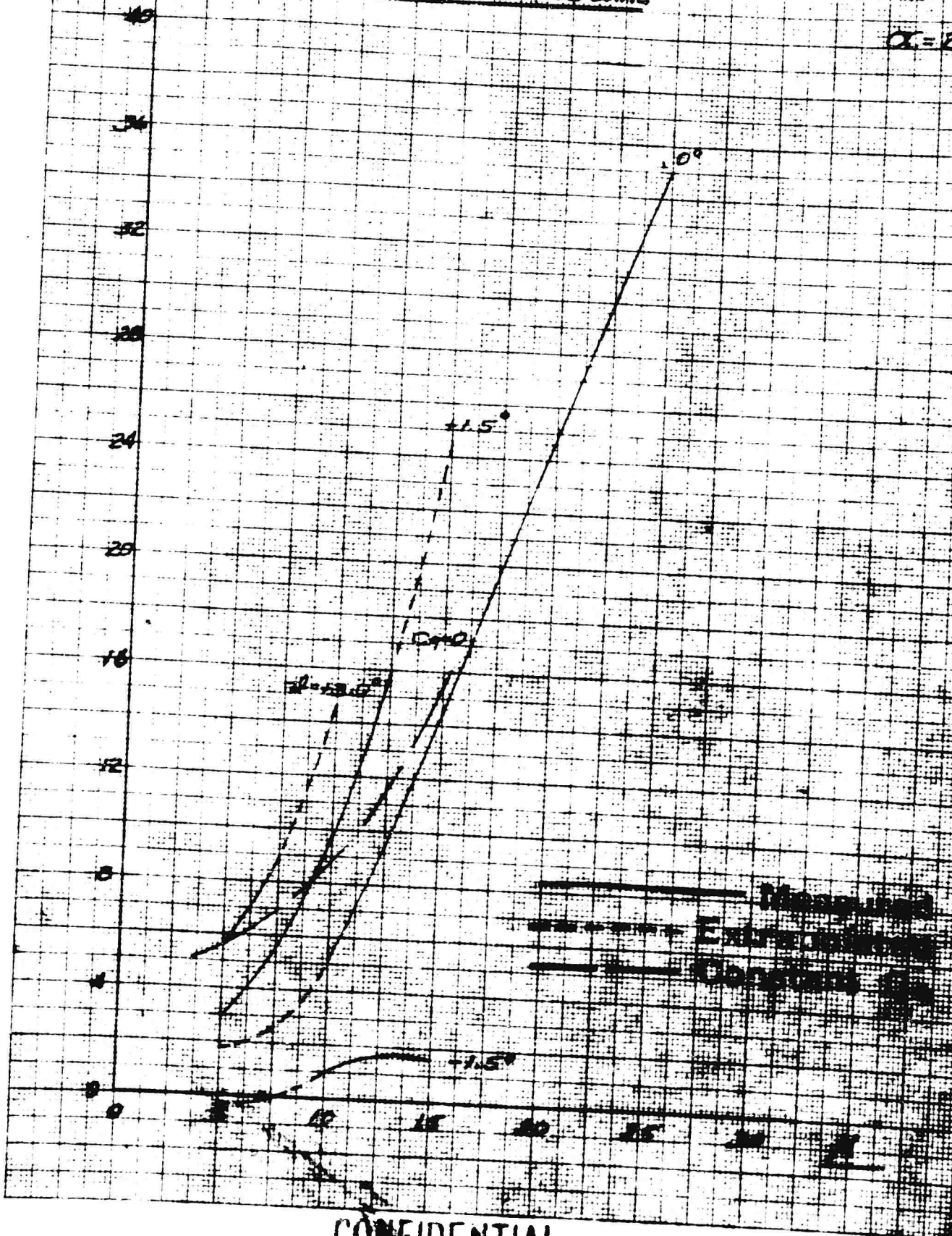
C_T vs μ

UNAL OCT 49 TESTS
WITHOUT HUB DRAG

B_0

$\alpha = 2^\circ$

$10^3 C_T$

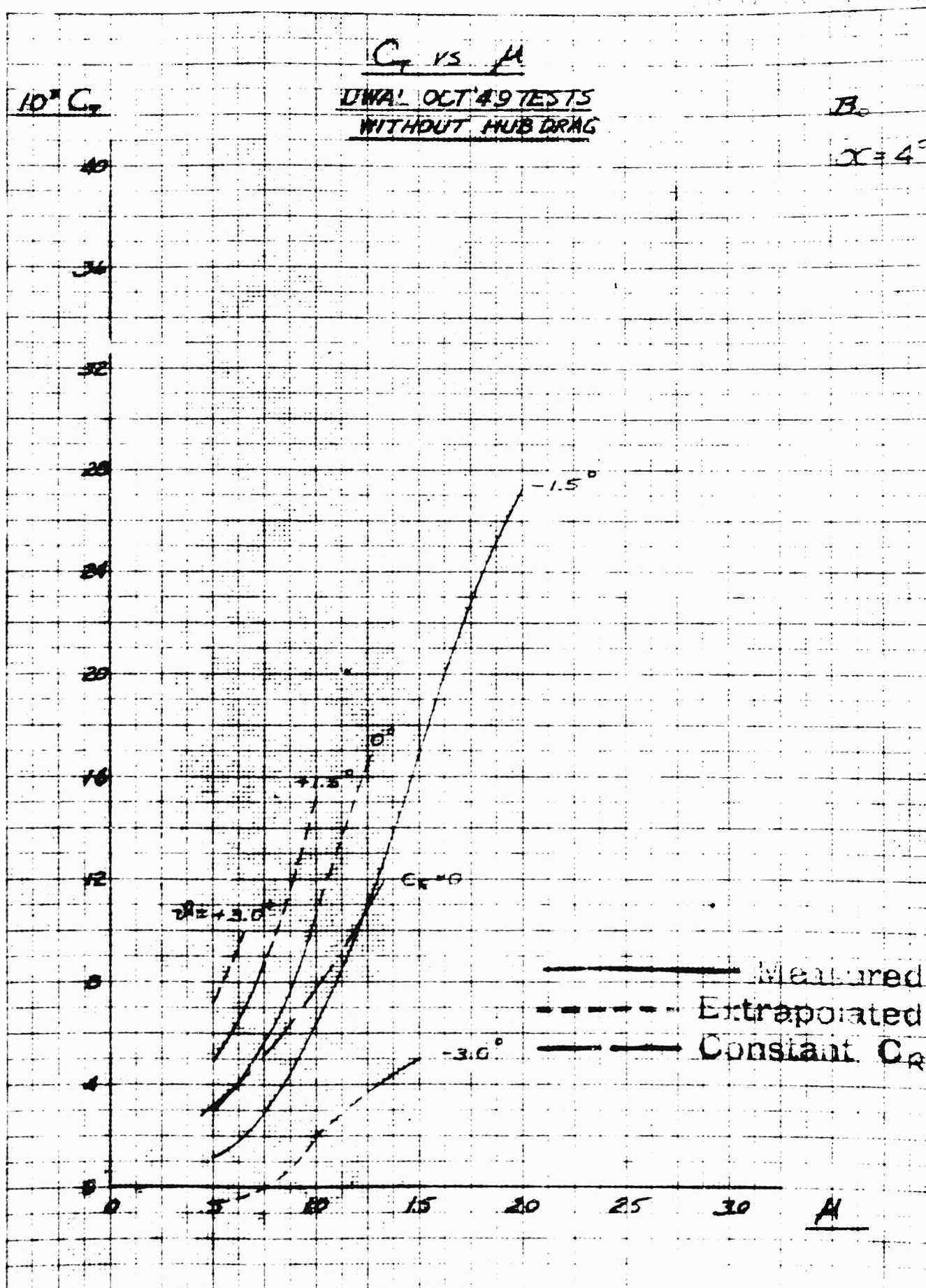


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NEUTREL & T-4 R CO

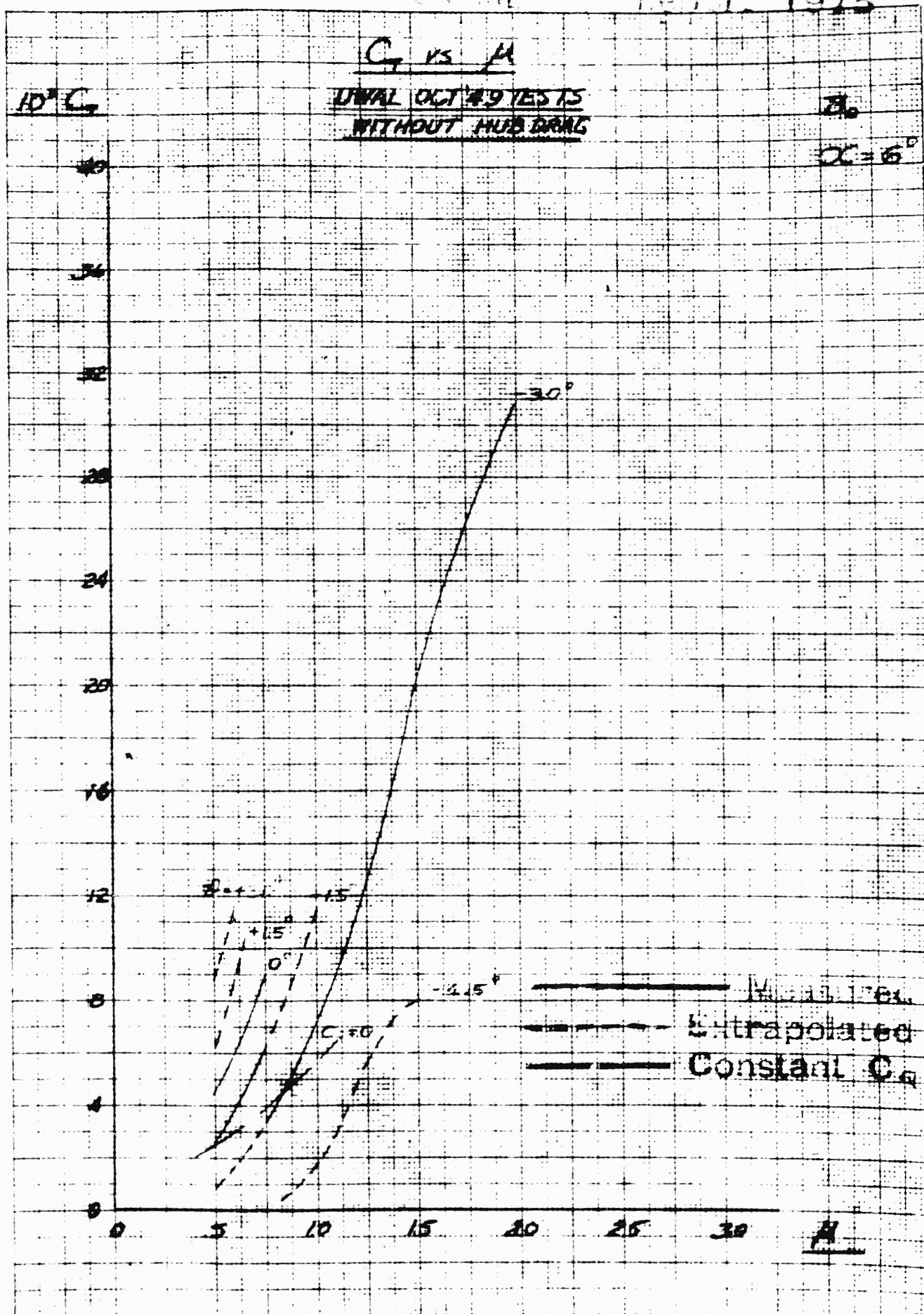
No. 359-11 Millimeter film lines & plotted on grid paper



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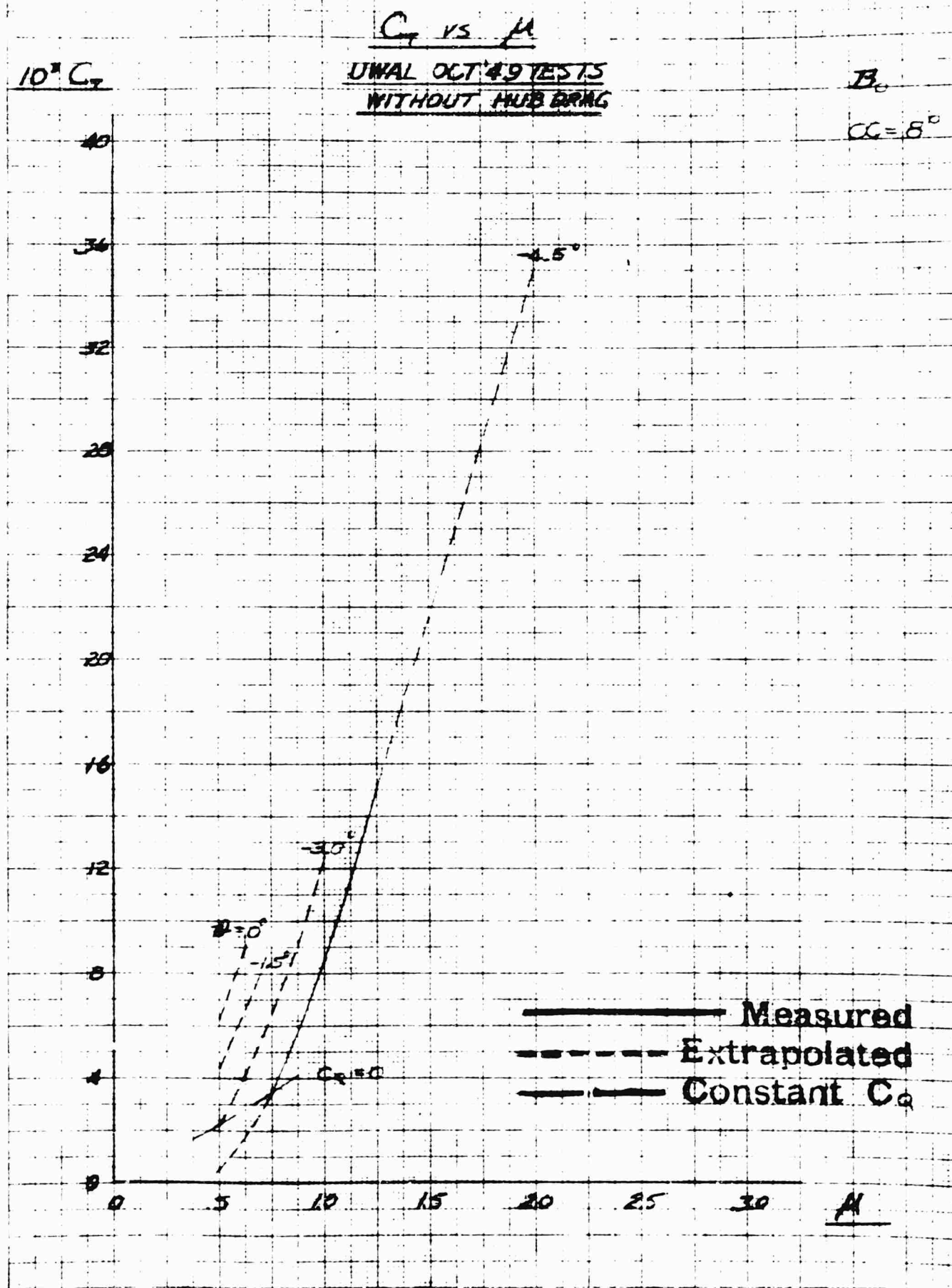
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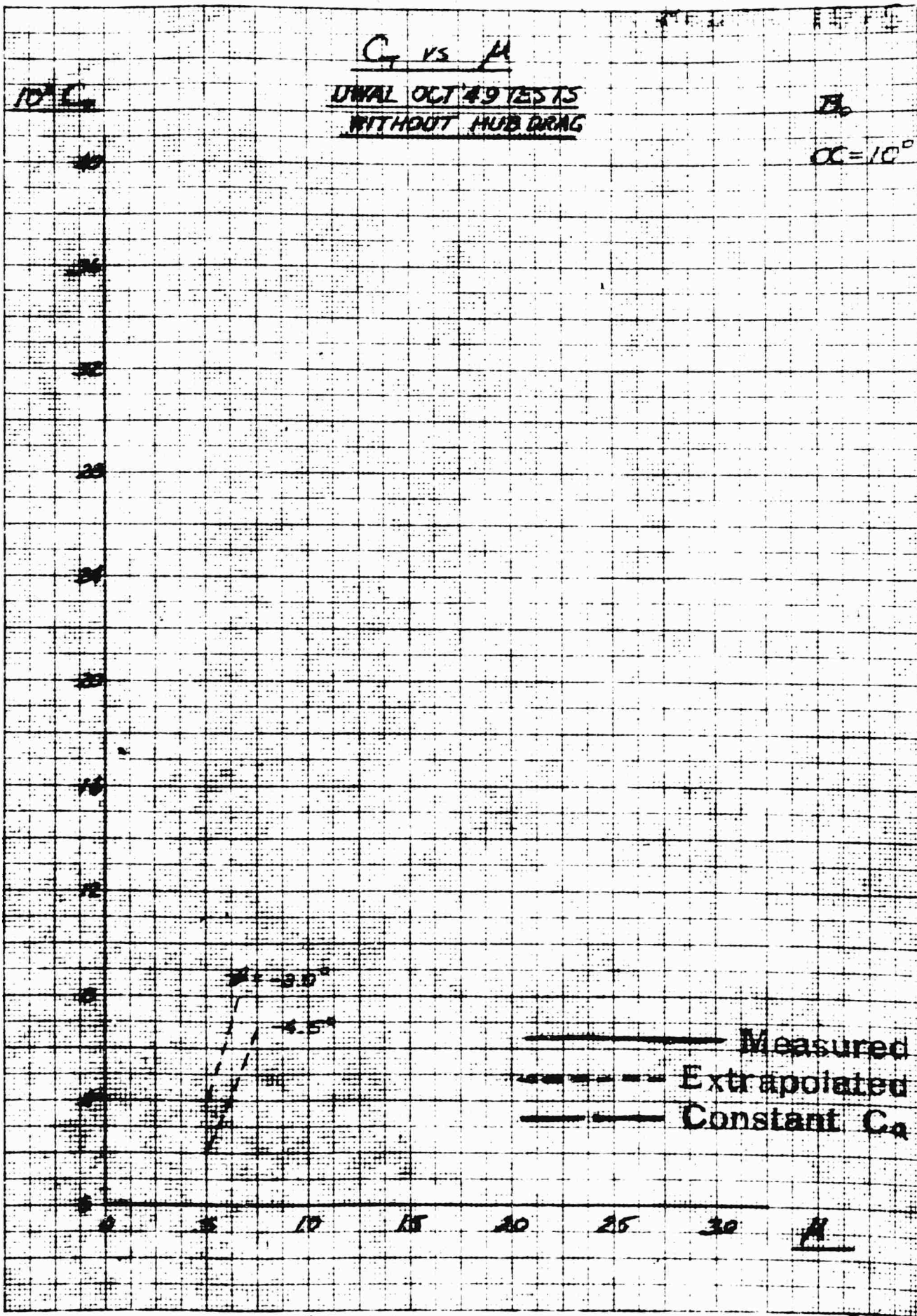
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KEUFFEL & ESSER CO

No. 559 14. Millimeters, 5 mm lines accented, cm lines heavy

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 C_D vs μ LINAL OCT '49 TESTS
WITHOUT HUB DRAG B_0 $\alpha = 0^\circ$ C_D

.010

.009

.008

.007

.006

.005

.004

.003

.002

.001

0

.5

1.0

1.5

2.0

2.5

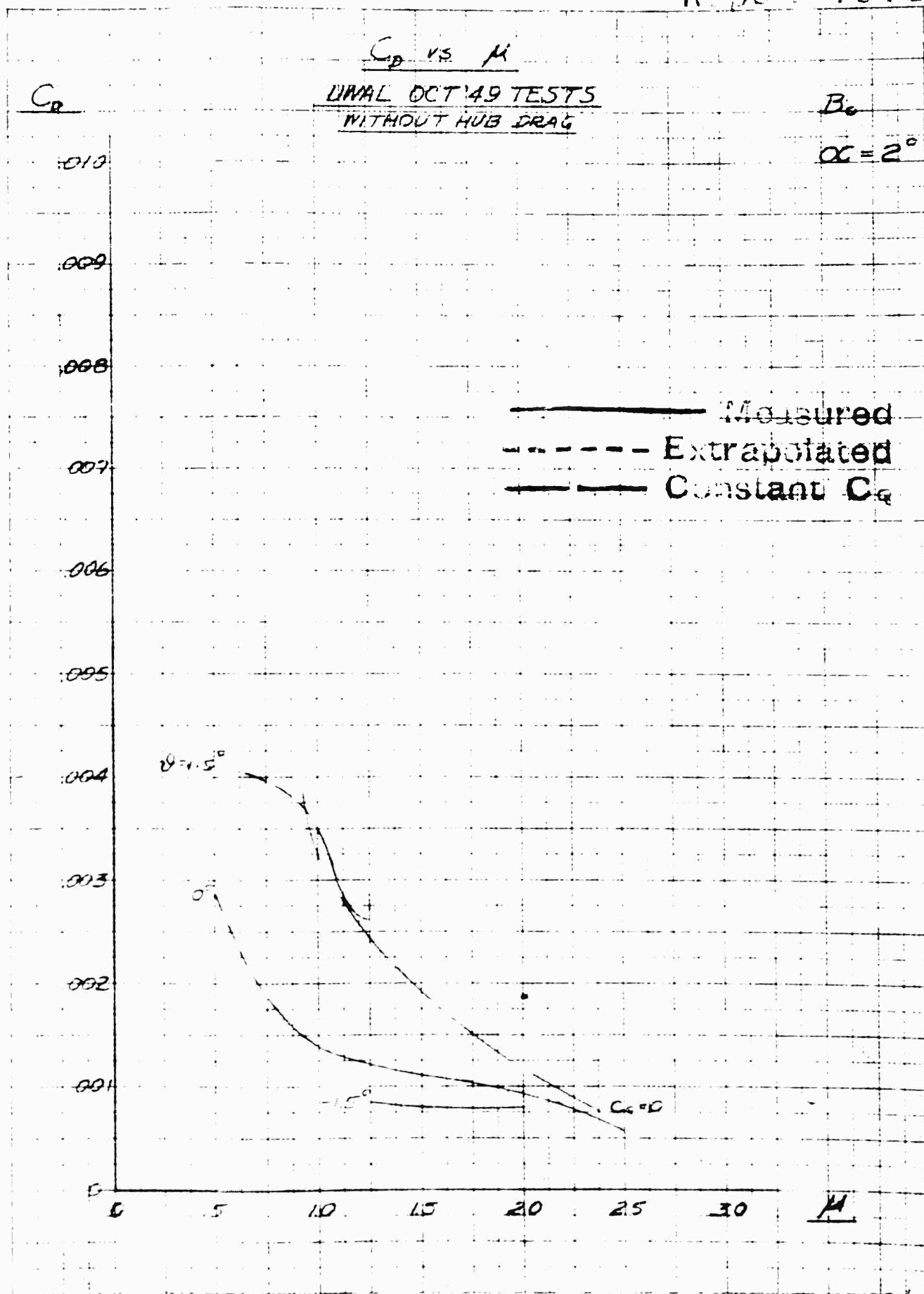
3.0

 μ

Measured
Extrapolated
Constant C_D

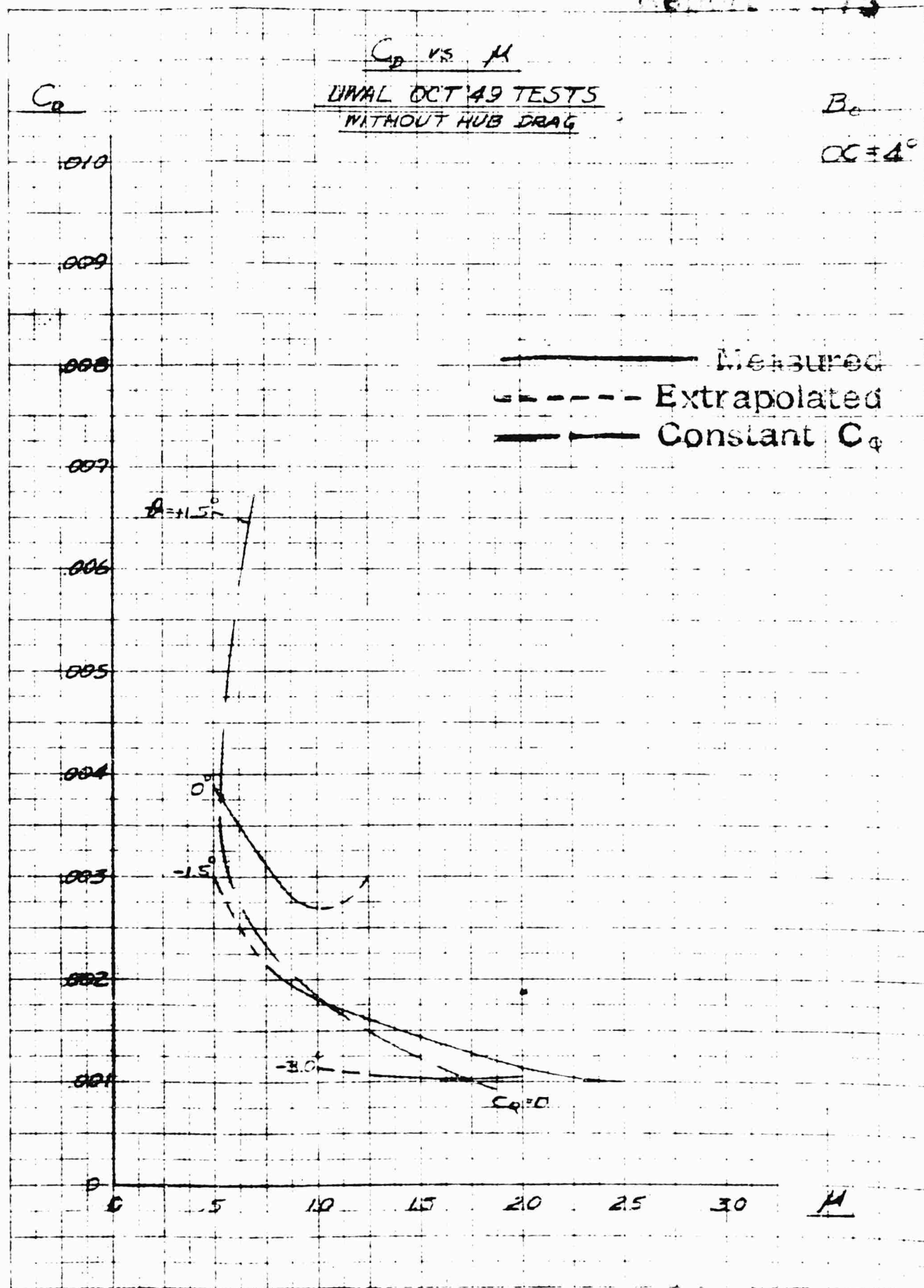
 $\alpha = +3.0^\circ$ $+1.5^\circ$ $C_D = 0$

CON-111

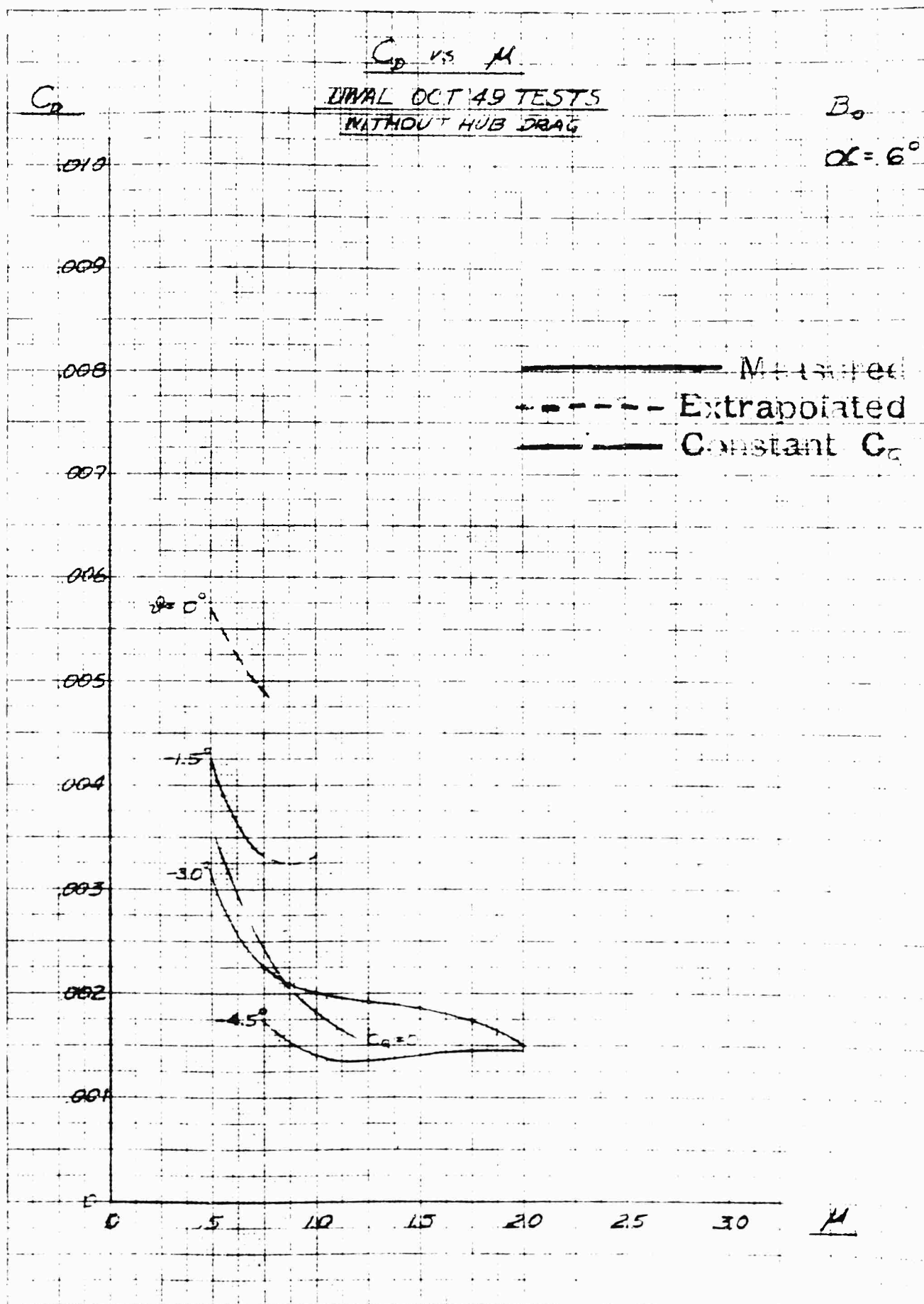


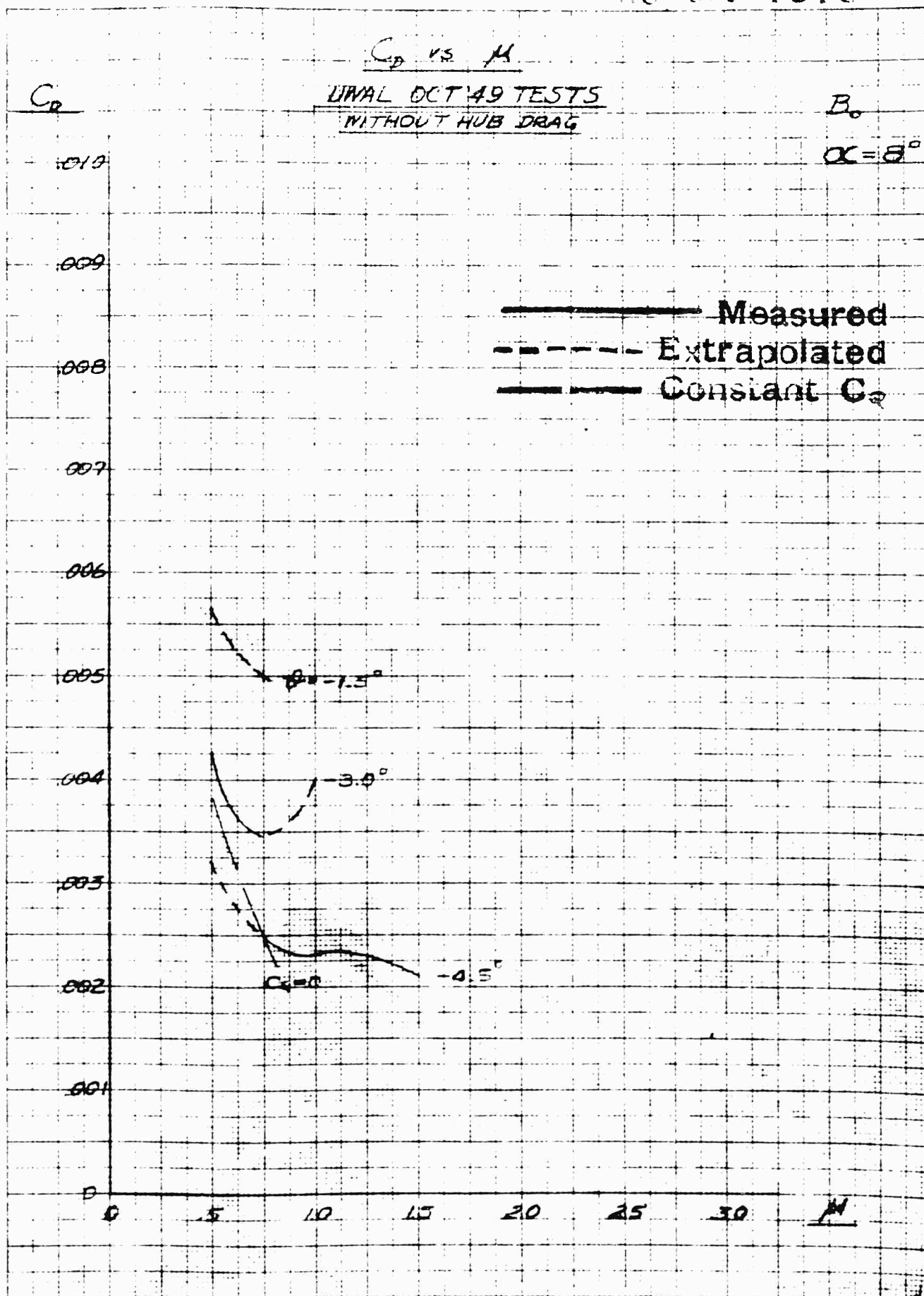
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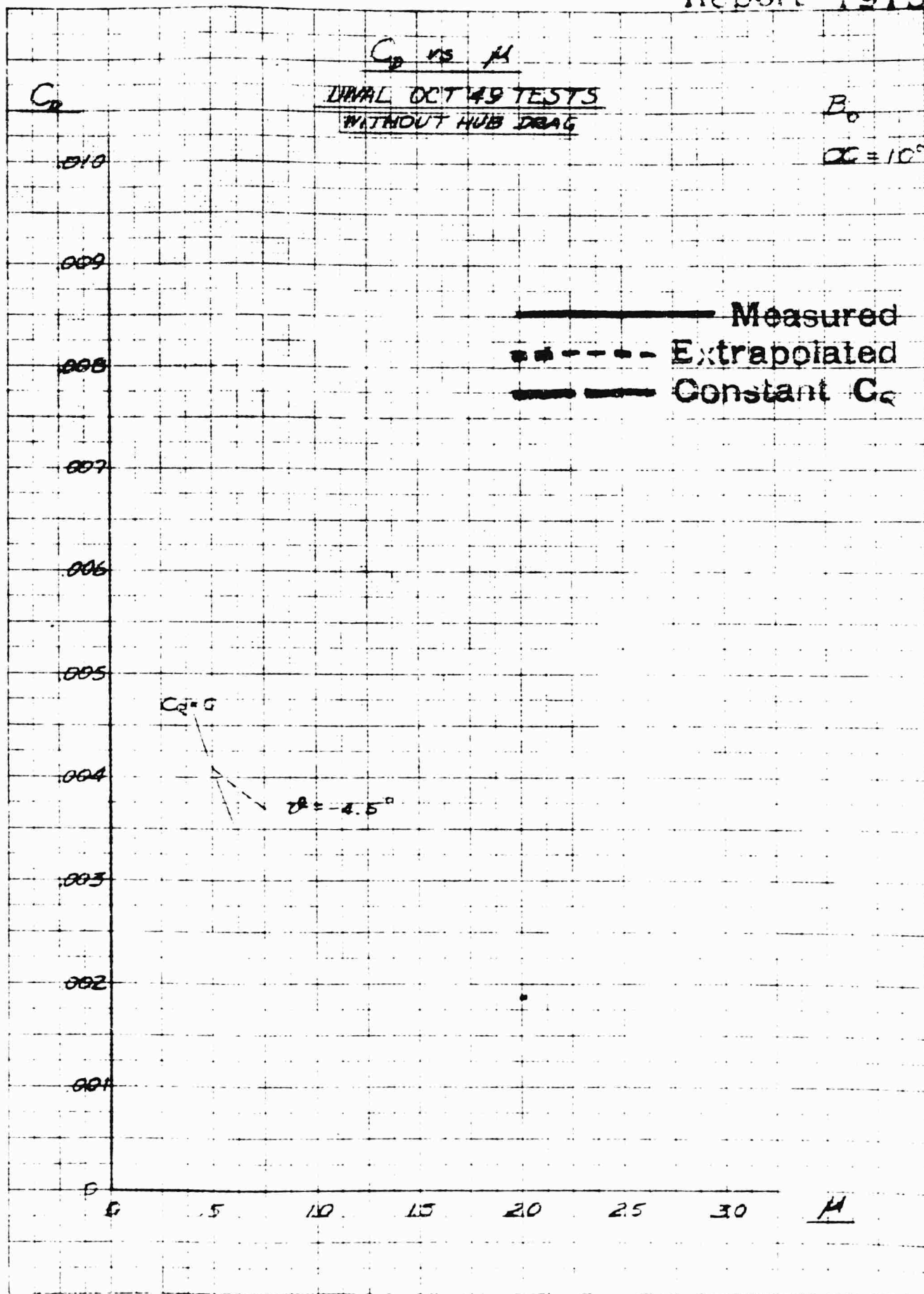
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L/D vs M

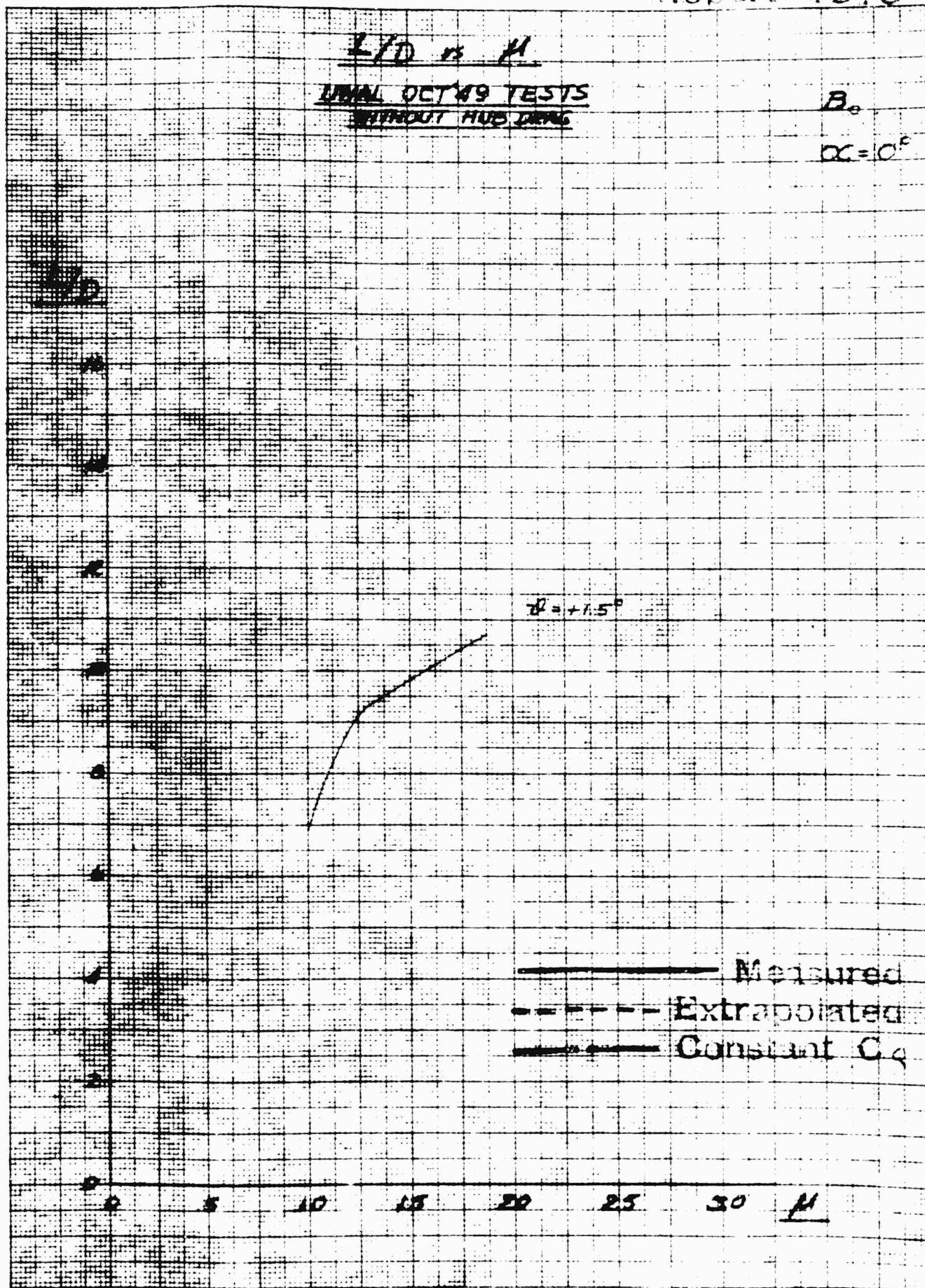
UNAL OCT 49 TESTS
WITHOUT HUB DRAG

B_0

$\alpha = 0^\circ$

$\theta = +1.5^\circ$

————— Measured
----- Extrapolated
----- Constant C_q



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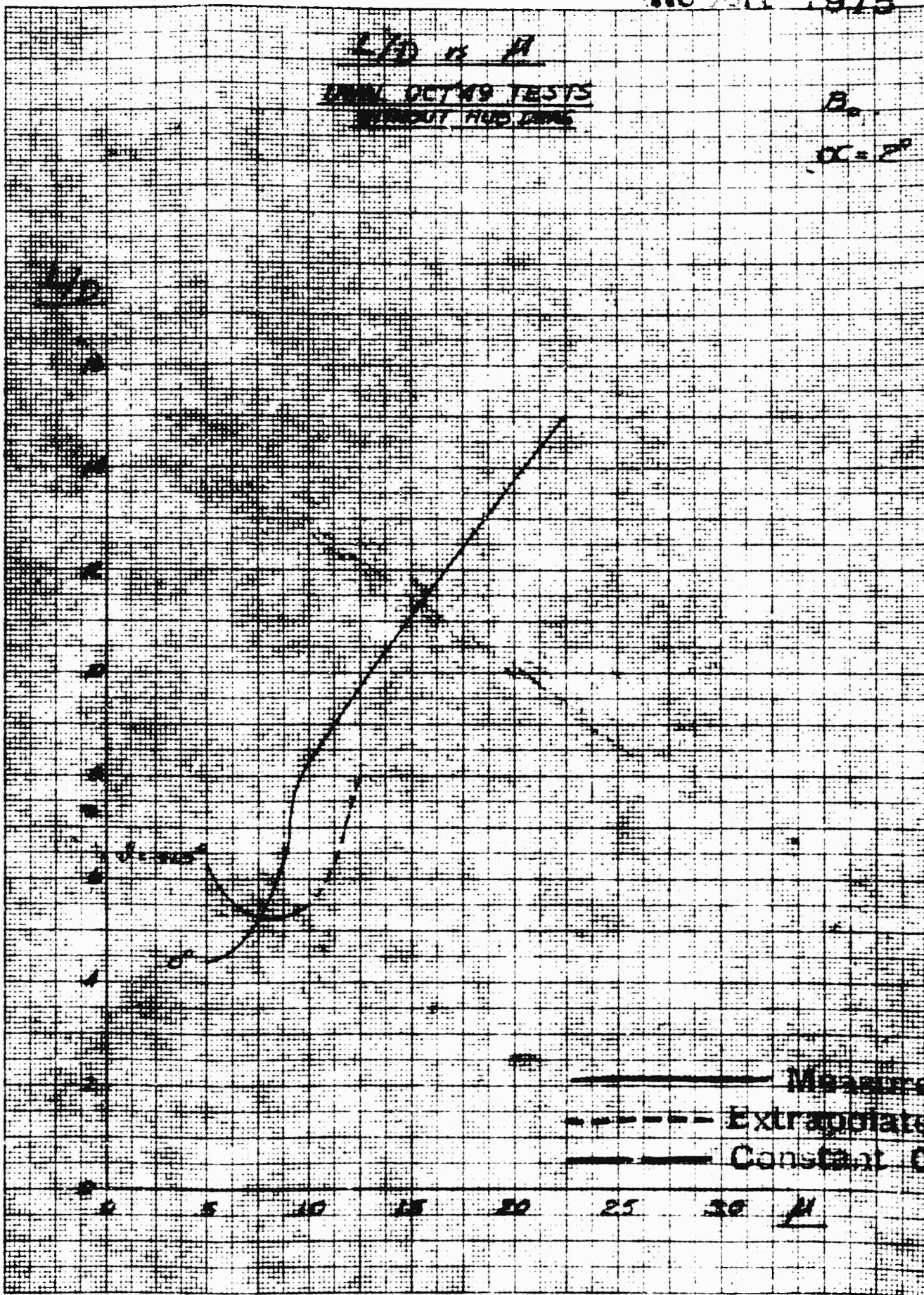
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L/D vs μ

DATA OCT 49 TESTS
WITHOUT HUB DRAG

B_0

$\alpha = 2^\circ$



————— Measured
----- Extrapolated
-.-.-.- Constant C_0

0 5 10 15 20 25 30 μ

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KEUFFEL & ESSER CO.

No. 359 14 Millimeters, 5 mm lines centered, cm lines heavy
MADE IN U.S.A.

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Record 1375

L/D is μ

UNAL OCT 19 TESTS
WITHOUT HUB DRAG

B_0

$\alpha = 4^\circ$

L/D

16

14

12

10

8

6

4

2

0

5

10

15

20

25

30

μ

-1.5°

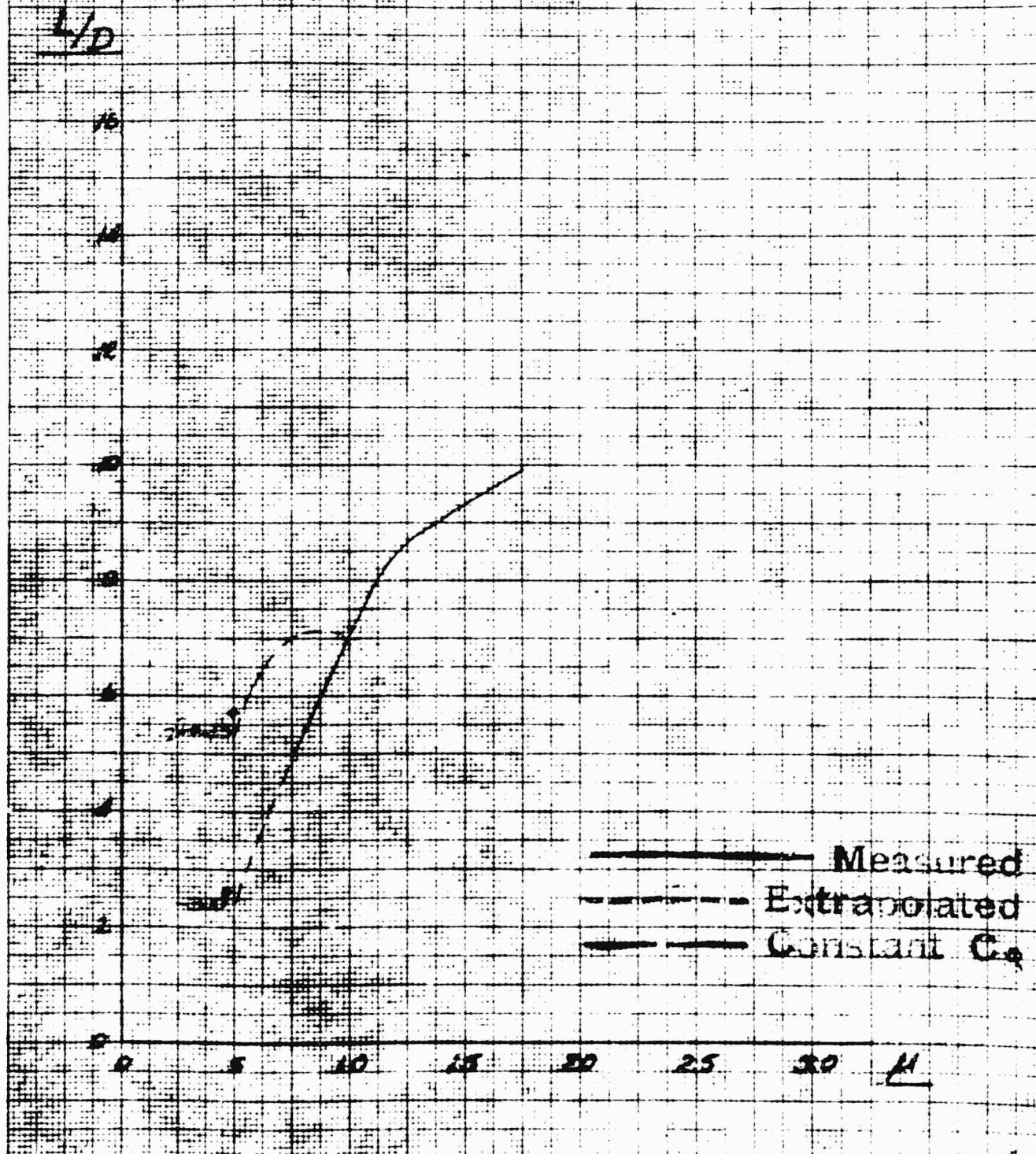
2.0°

————— Measured
----- Extrapolated
————— Constant C_R

KEUFFEL & ESSER CO.

No. 35914 Millimeters, 5 mm lines accented, cm lines heavy

L/D vs μ
UNAL OCT 49 TESTS
WITHOUT HUB DRAG

 B_0 $\alpha = 6^\circ$ 

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L/D vs H

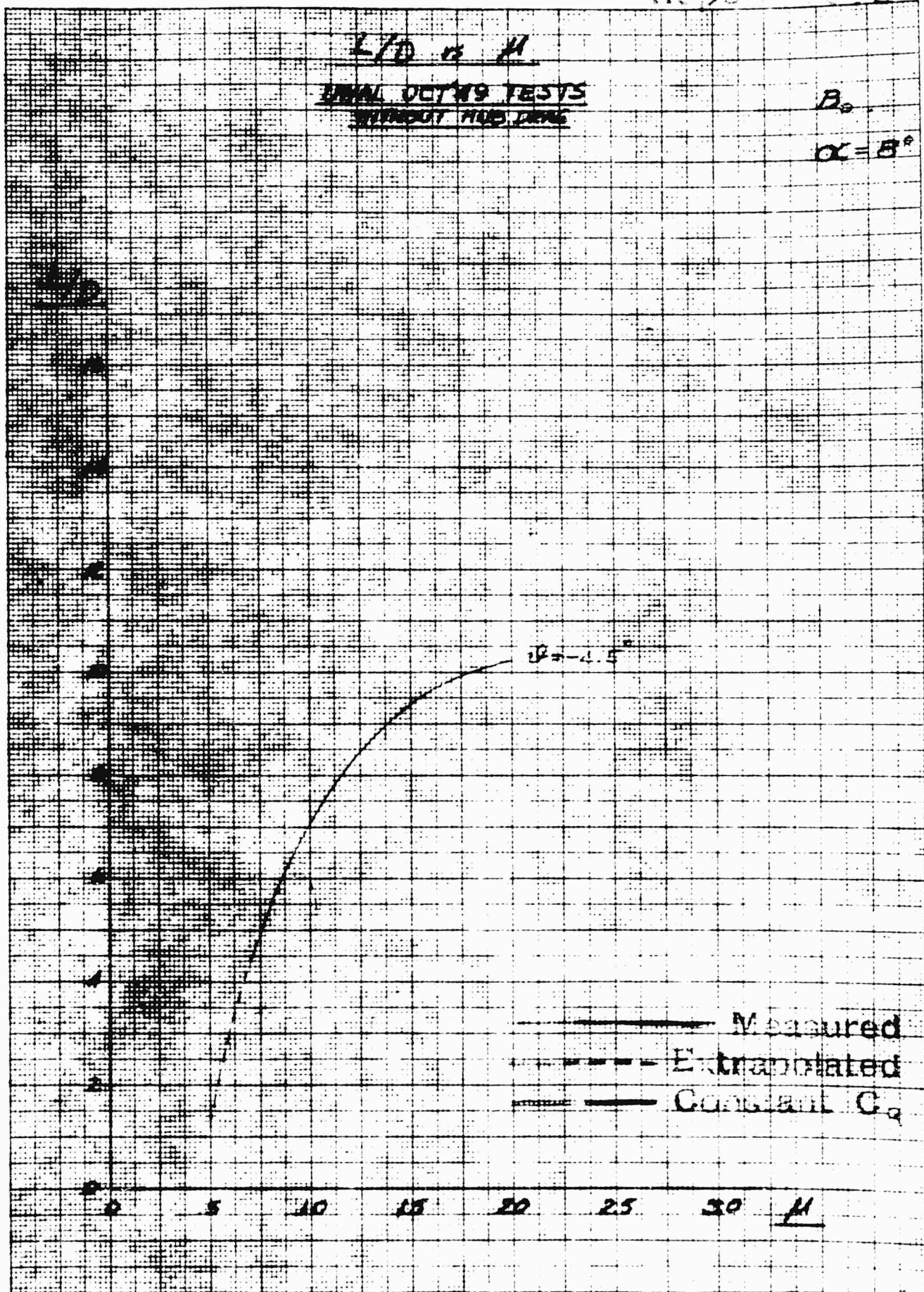
INITIAL OCT 19 TESTS
WITHOUT FUEL DROPS

B_0

$\alpha = B^0$

KEUFFEL & ESSER CO.

No. 359 11 Millimeters, 5 mm lines accented, cm lines heavy



L/D vs μ

UNAL OCT 49 TESTS
WITHOUT HUB DRAG

B_0

$\alpha = 10^\circ$

L/D

16

14

12

10

8

6

4

2

0

0

5

10

15

20

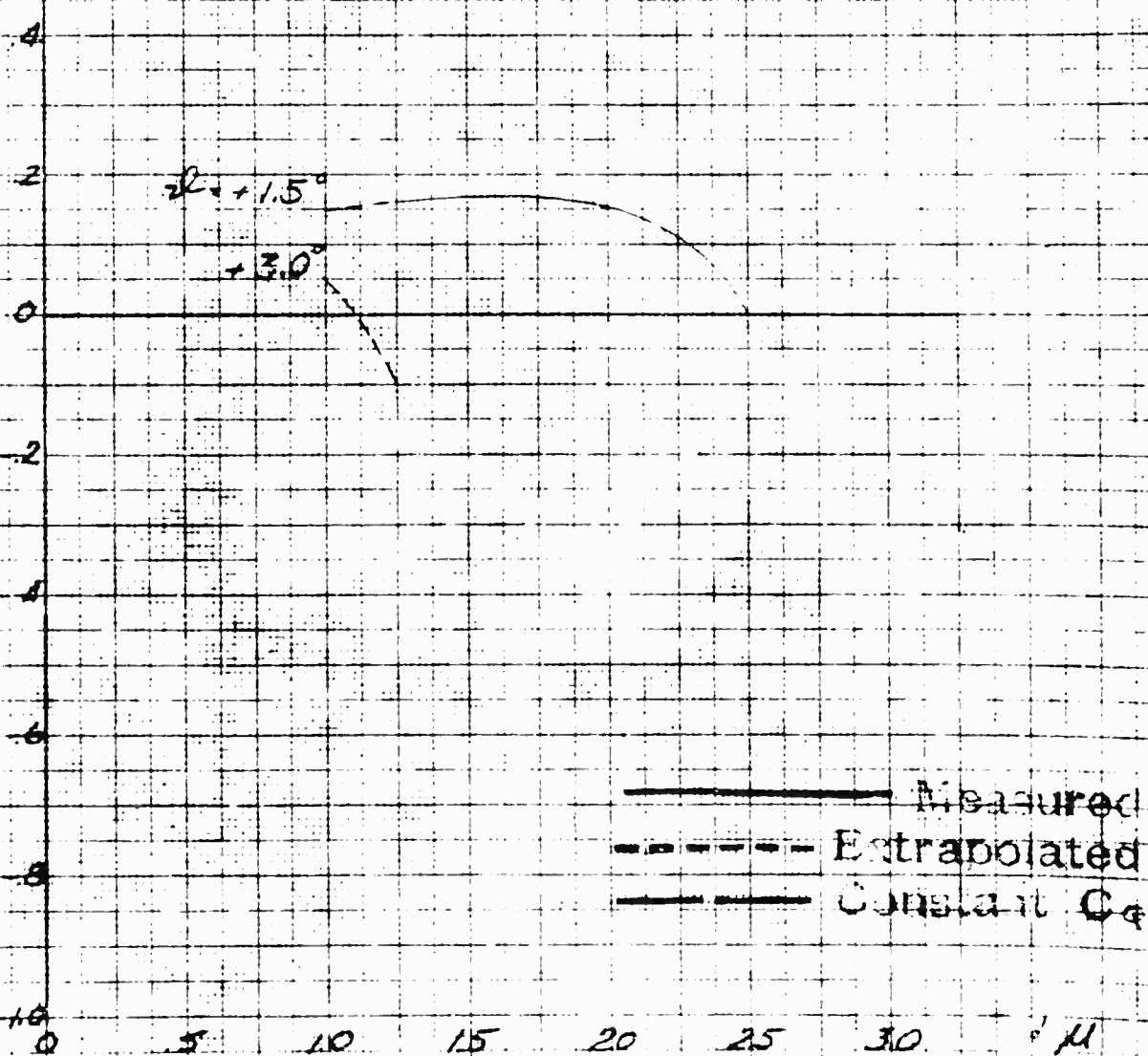
25

30

μ

$\mu = 4.5^\circ$

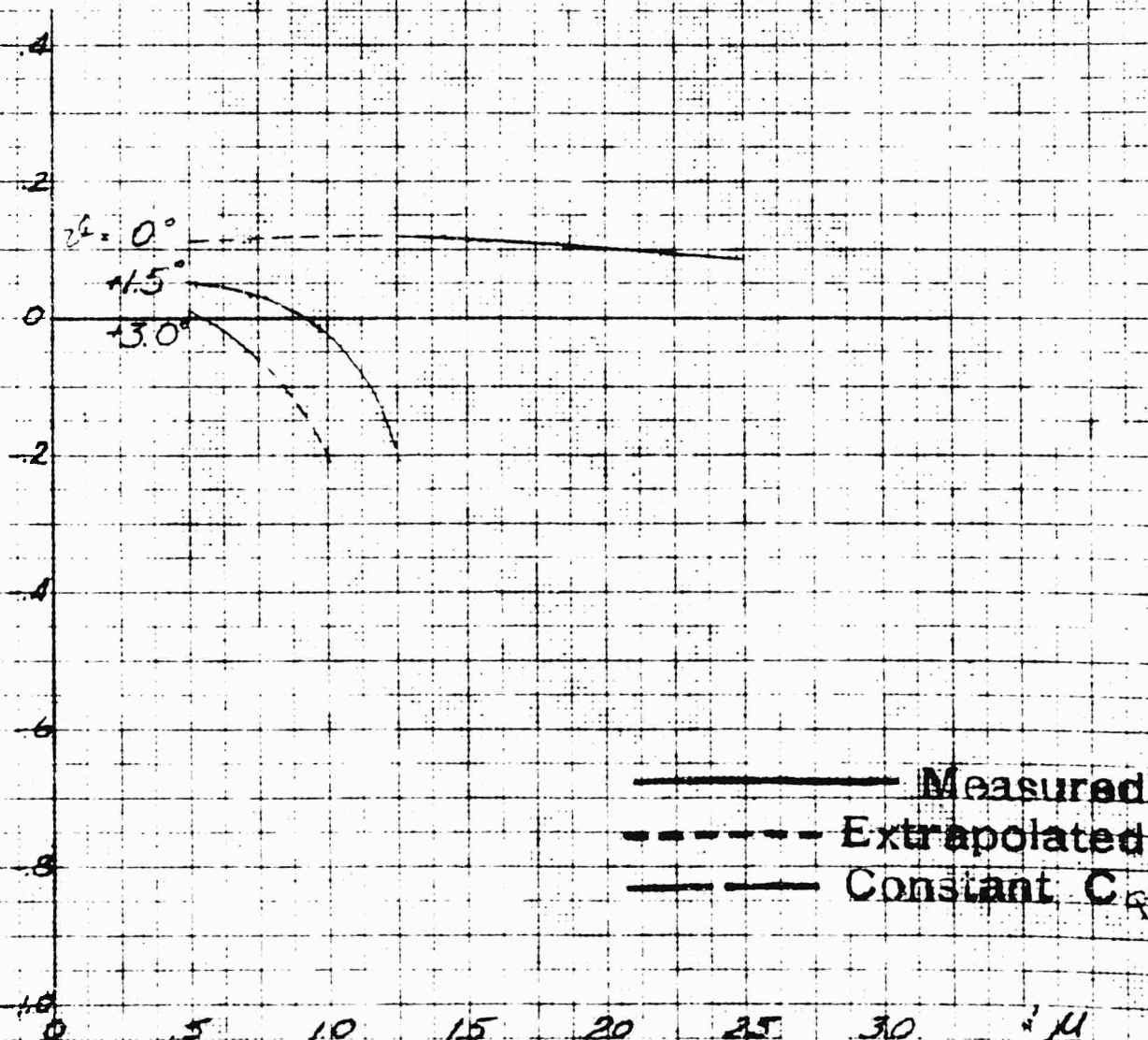
———— Measured
----- Extrapolated
———— Constant C_0

C_D vs μ UWAL OCT 49 TESTS
WITHOUT HUB DRAGB $\alpha = 0^\circ$ $10^3 C_D$ 

C_D vs μ
UWAL OCT 49 TESTS
WITHOUT HUB DRAG

B_0
 $\alpha = 2^\circ$

$10^3 C_D$



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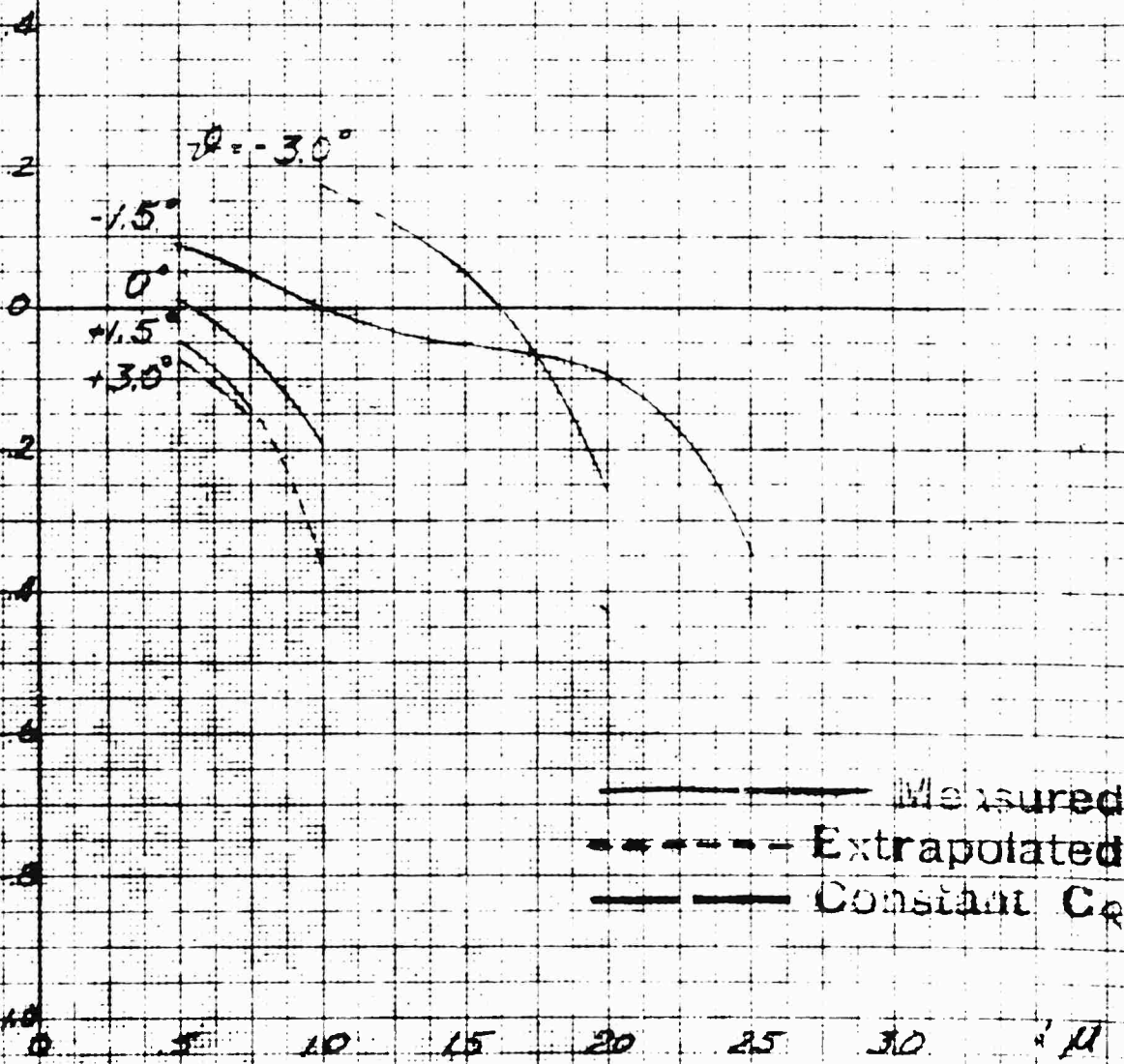
C_D vs μ

UWAL OCT 49 TESTS
WITHOUT HUB DRAG

B_0

$\alpha = 4^\circ$

$10^3 C_D$



KEUFFEL & ESSER CO.

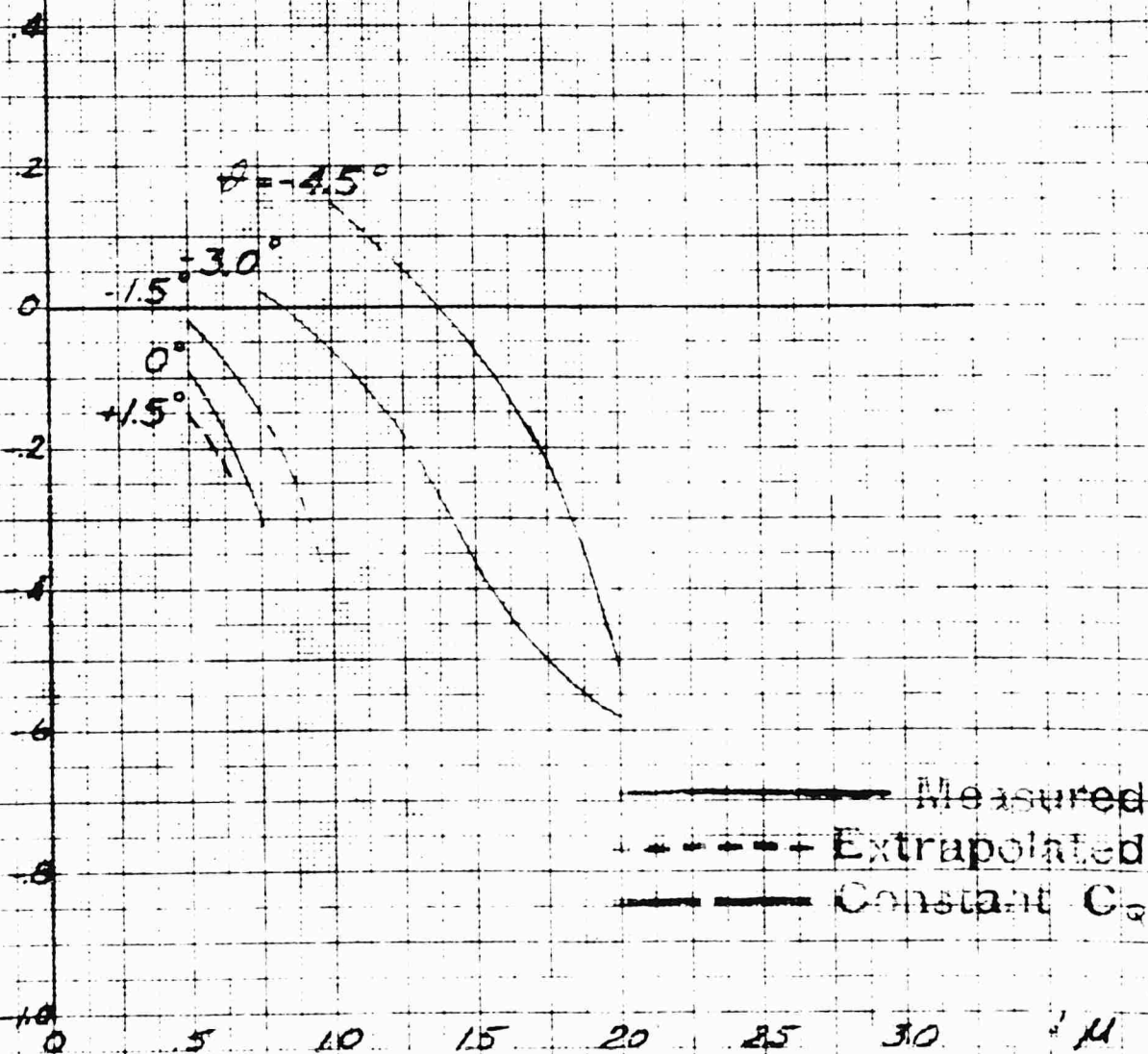
No. 359-14 Millimeters, 5 mm lines acented, cm lines heavy

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C vs A

UWAL OCT 49 TESTS
WITHOUT HUB DRAG

B

$$\alpha = \alpha'$$
 $10^{\circ}C_2$ 

7021

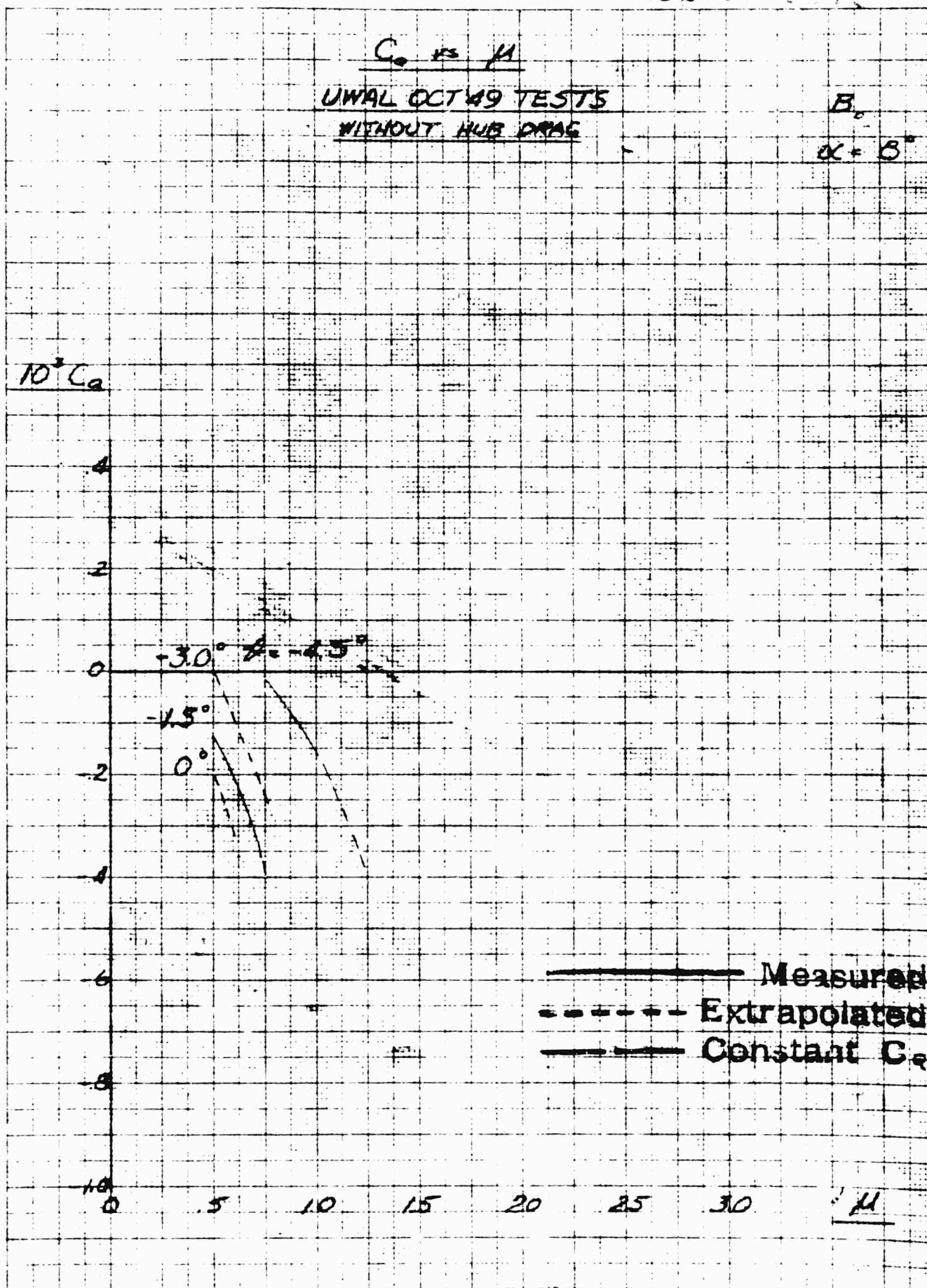
UWAL OCT 49 TESTS
WITHOUT HUB DRAG

Б

$$\alpha = \beta$$

NEUFEL & ESSER CO.

are 1500 and 1000 ft. respectively.



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140

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150

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C_D vs μ

UWAL OCT 49 TESTS
WITHOUT HUB DRAG

B_c

$\alpha = 10^\circ$

$10^3 C_D$

$\theta = 4.5^\circ$

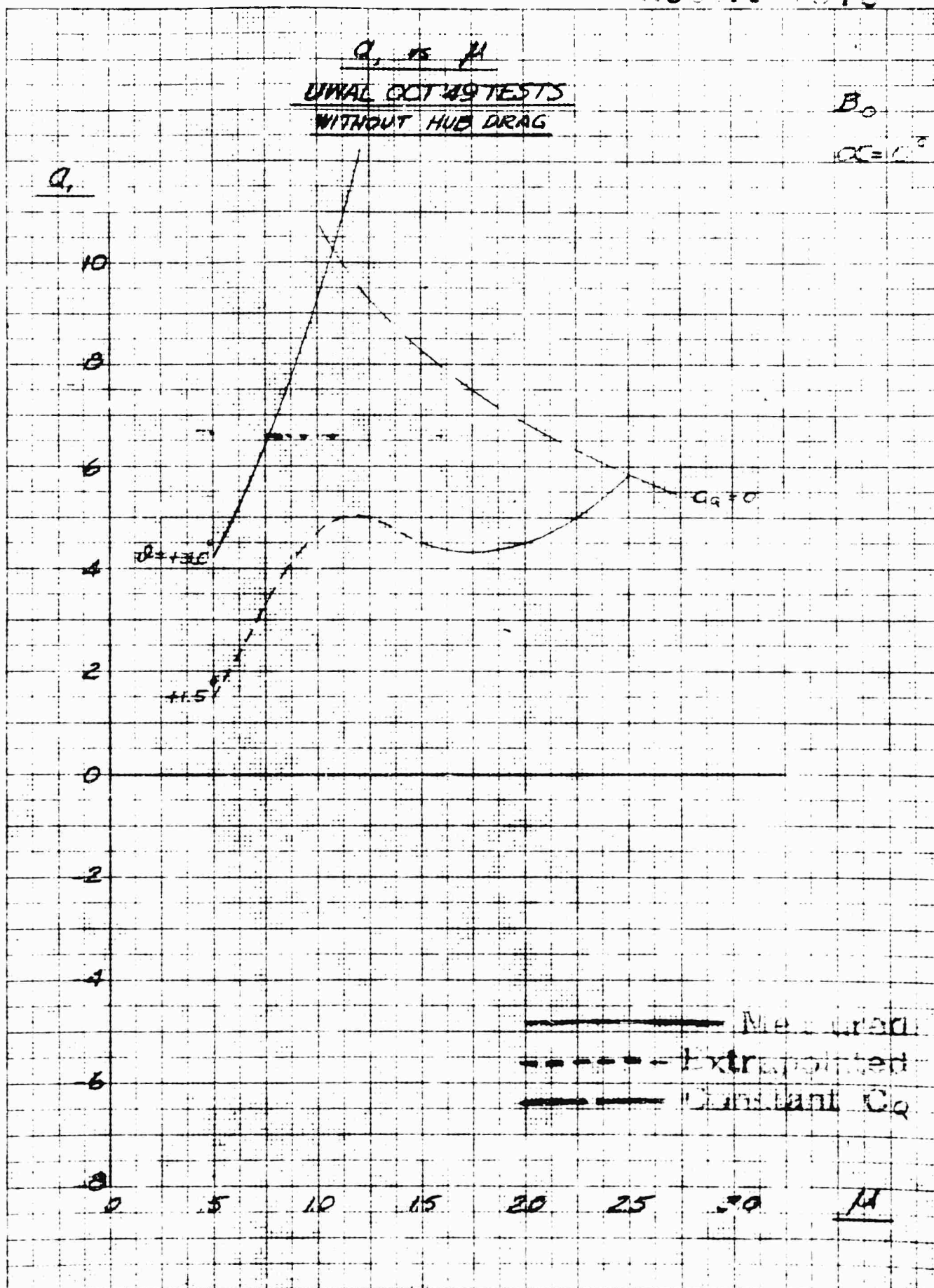
-30°

Measured
Extrapolated
Constant C_D

μ

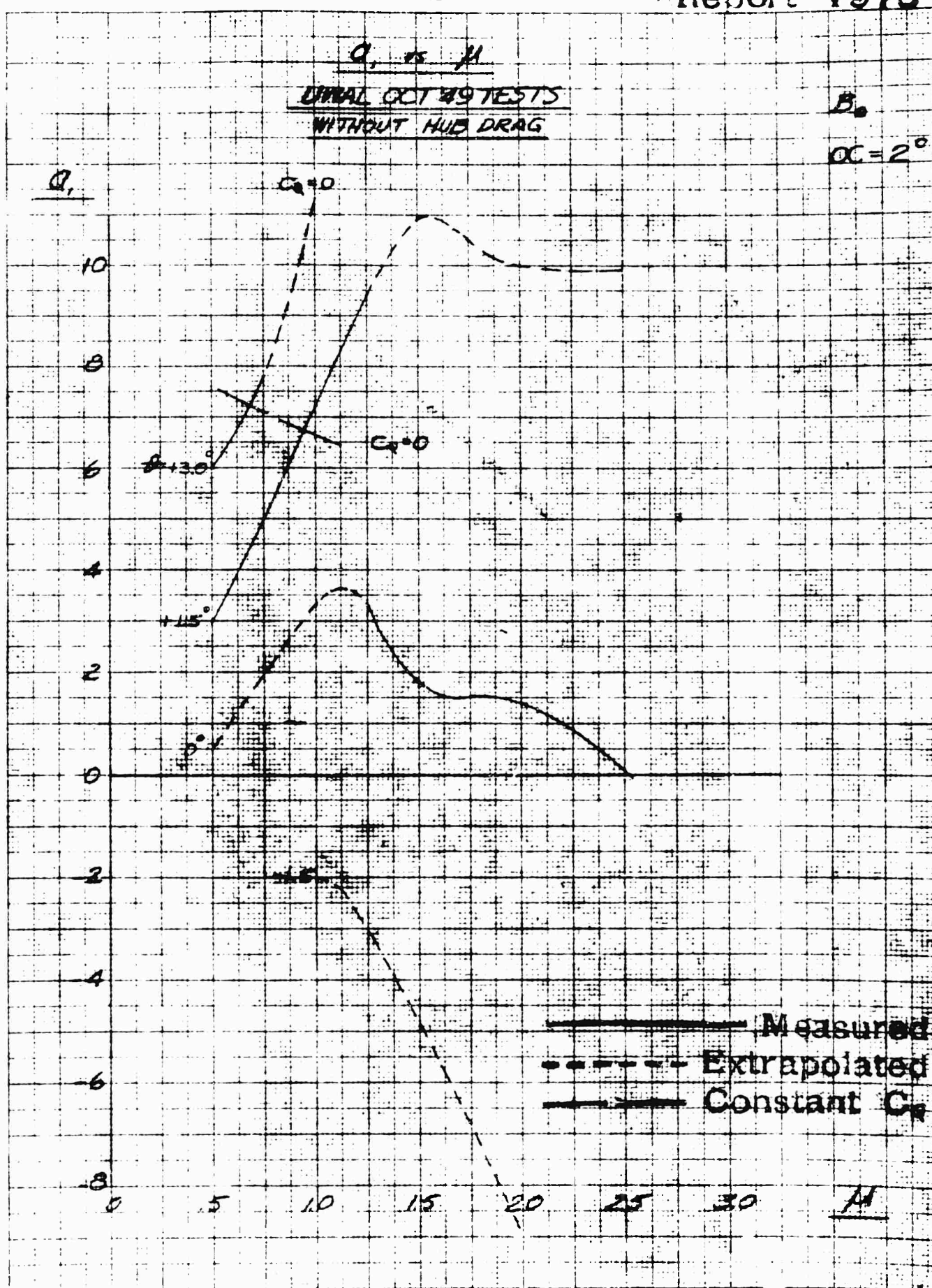
KEUFFEL & ESSER CO

No. 359 14. Millimeter, 5 mm lines at center, 10 mm lines heavy



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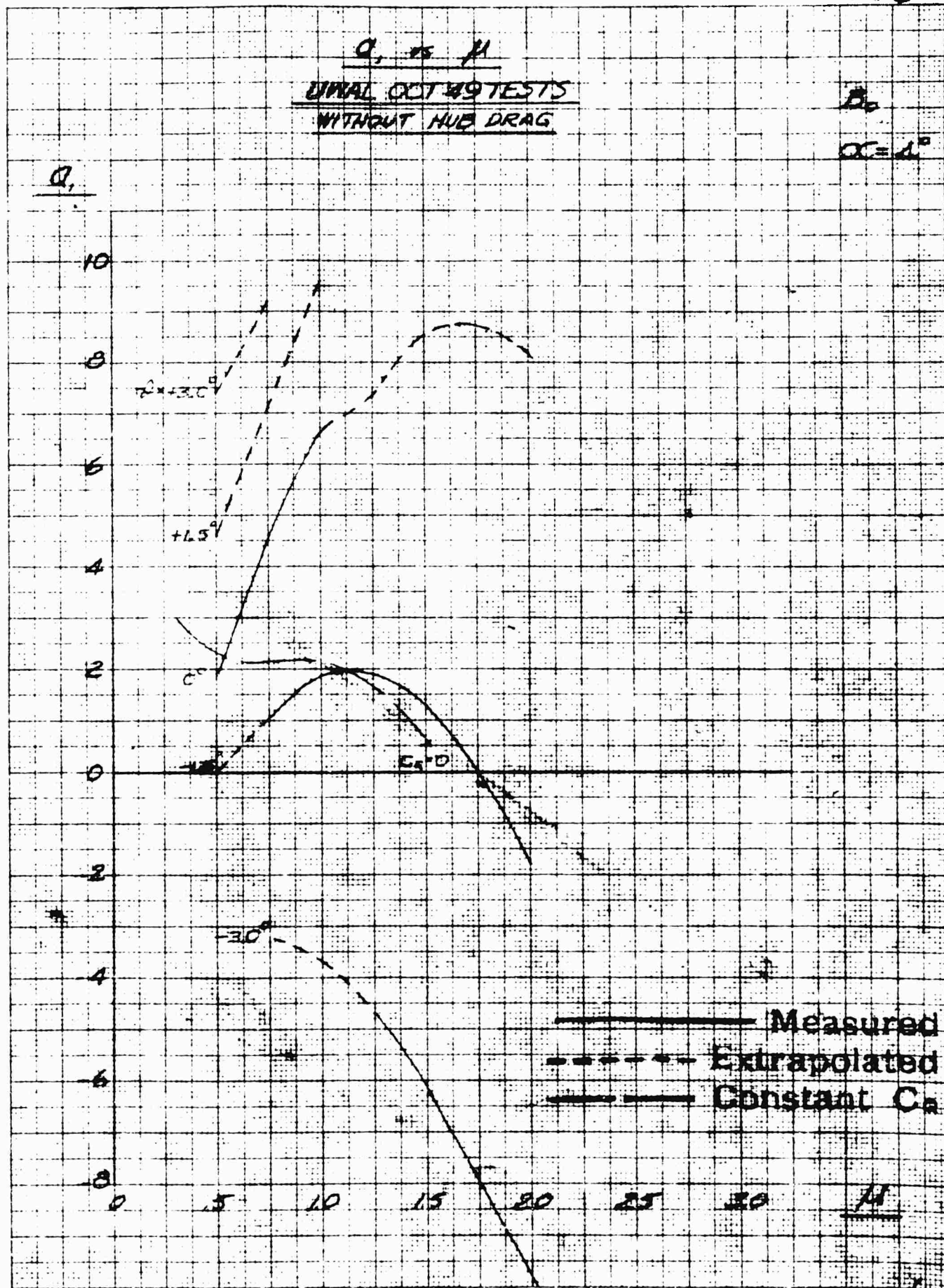
KEUFFEL & ESSER CO.

No. 359 14 Millimeters, 5 mm lines acented, cm lines heavy

12-14-45

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Q_1 vs μ
UNVAL OCT 49 TESTS
WITHOUT HUB DRAG

 B_0 $\alpha = 6^\circ$ Q_1

10

8

6

4

2

0

-2

-4

-6

-8

-1.5

-3.0

-4.5

 $Q_2 = 0$

———— Measured
 - - - - - Extrapolated
 ——— Constant C_d

0

5

10

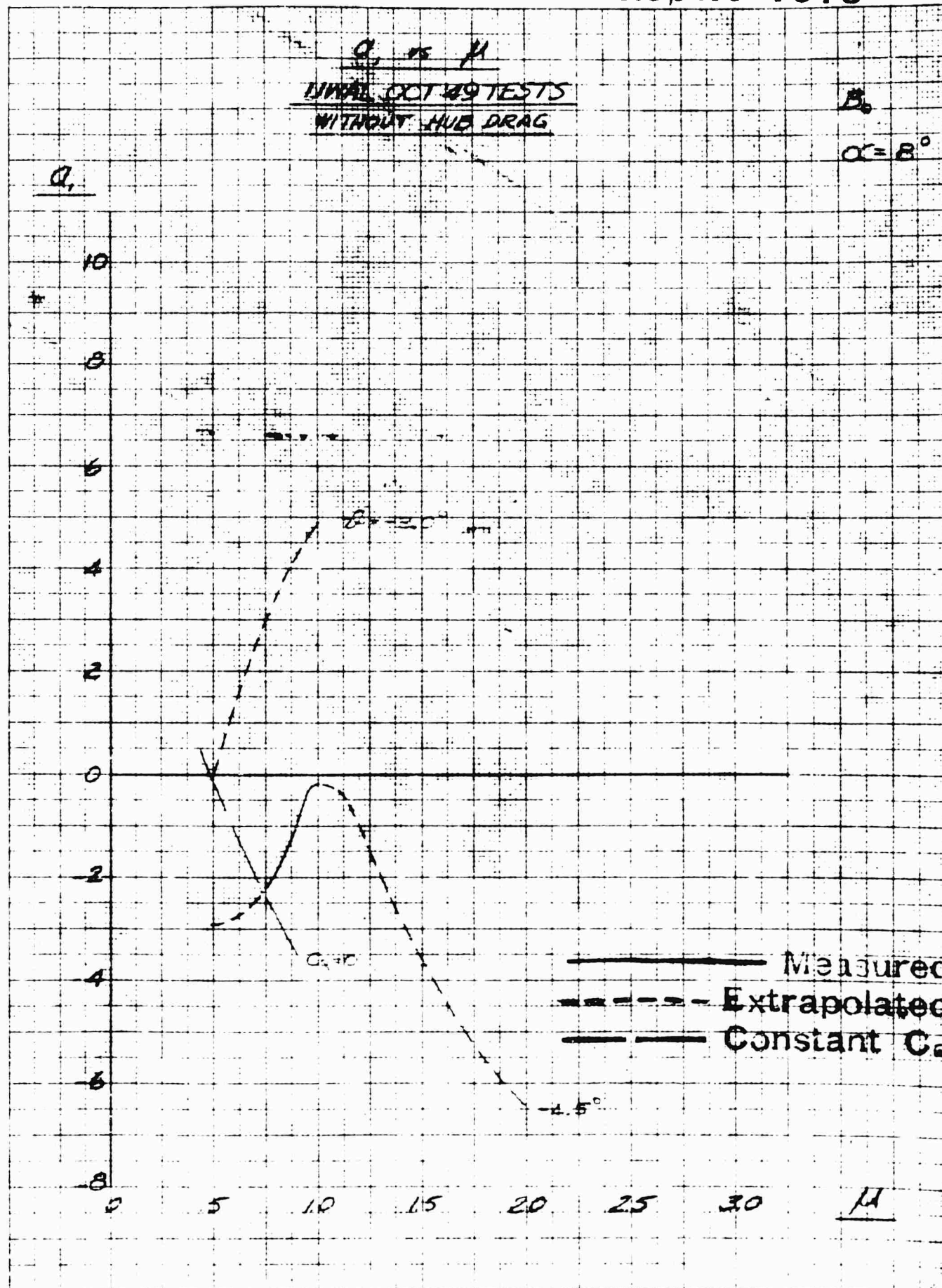
15

20

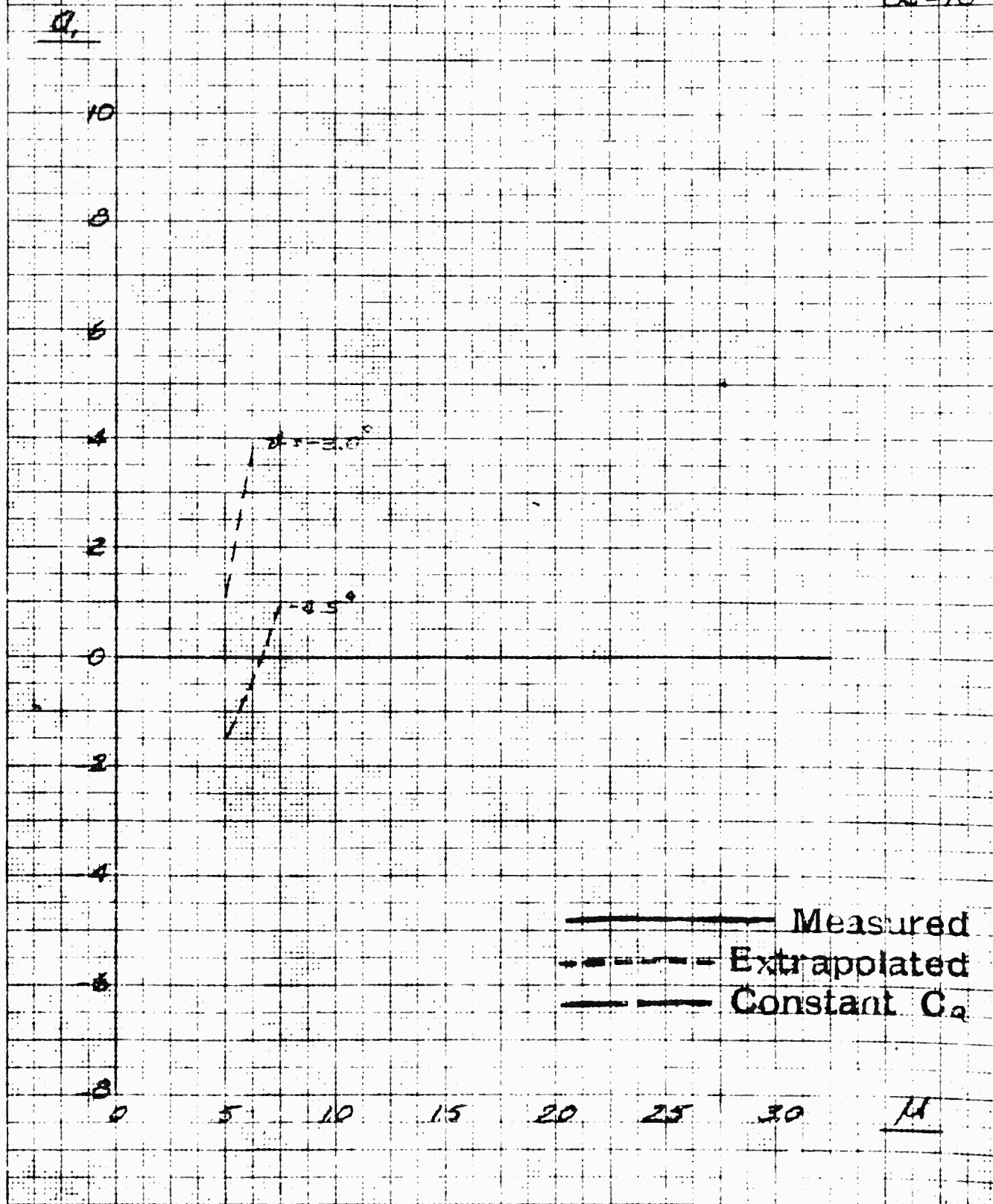
25

30

 μ

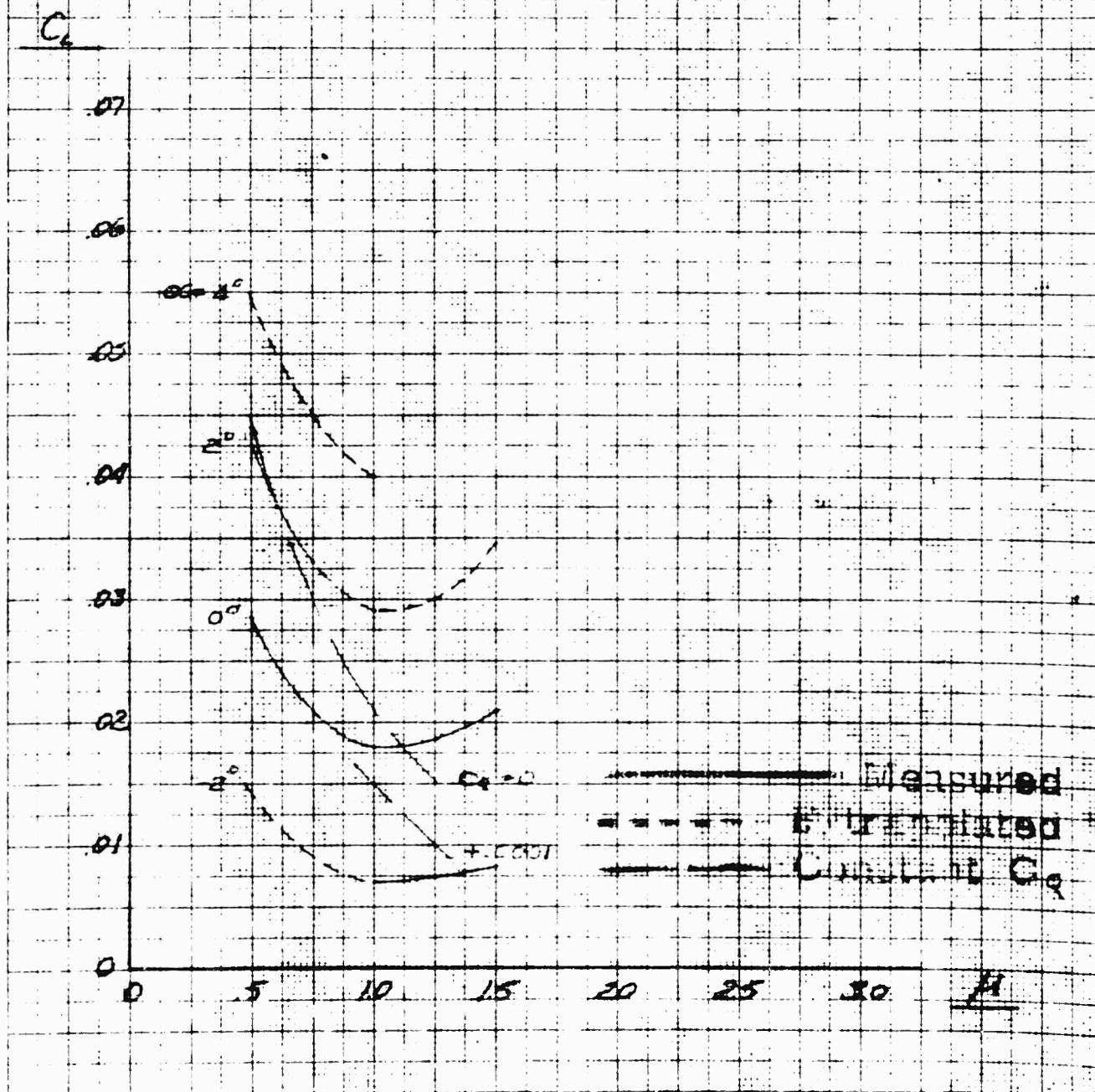


Q_1 vs μ
UNVAL OCT 49 TESTS
WITHOUT HUB DRAG

 B_0 $\alpha = 10^\circ$ 

C_L vs μ
UNVAL OCT 49 TESTS
WITHOUT HUB DRAG

B.
 $\beta = +30^\circ$



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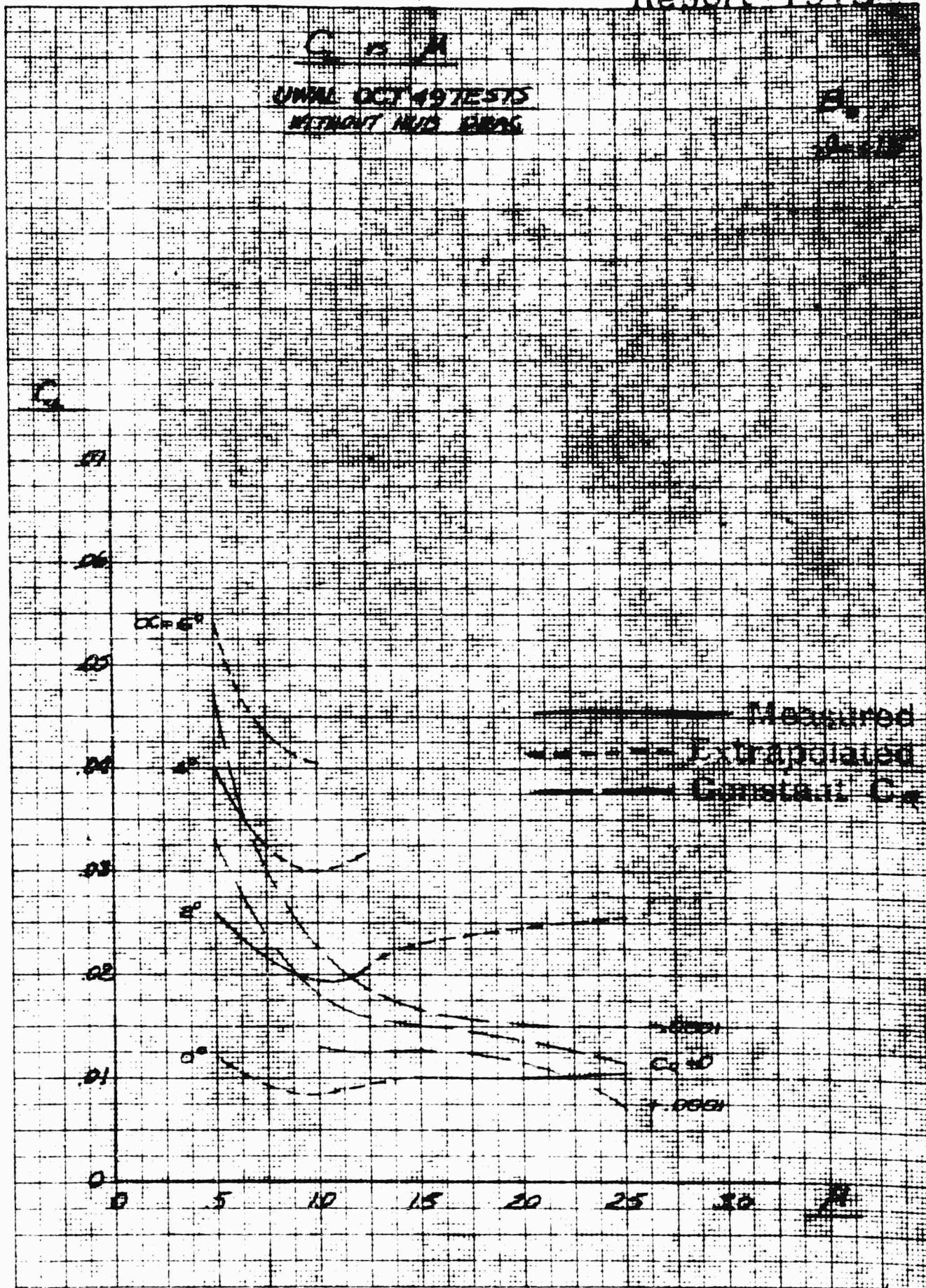
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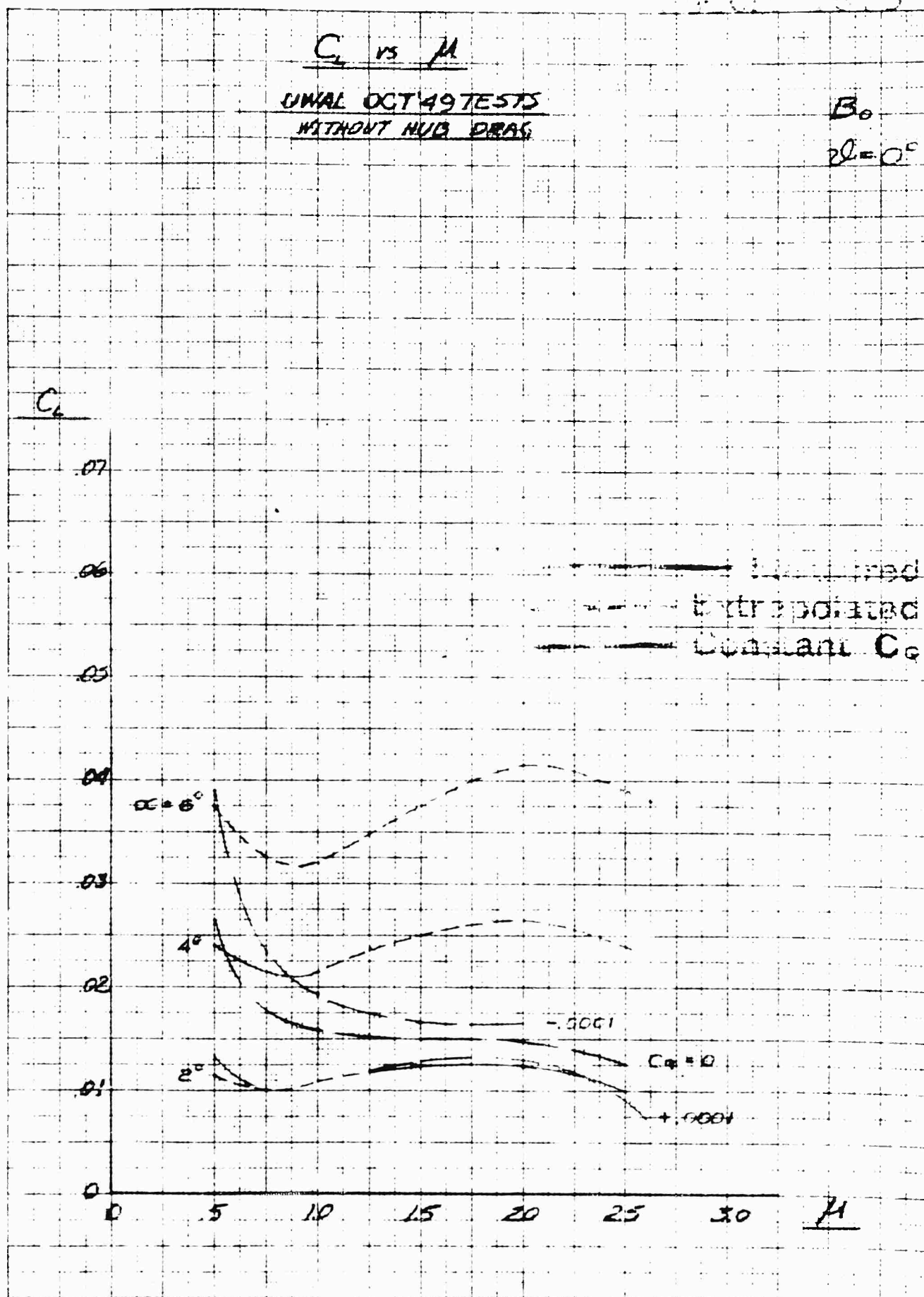
C is A

UNRA OCT 49 TESTS
WITHOUT HUD BRAG

KEUFFEL & ESSER CO.

No. 359 14. Millimeters, 5 mm lines centered, 60 lines heavy.



C_L vs μ UNVAL OCT 49 TESTS
WITHOUT HUB DRAG B_0 $\beta_0 = 0^\circ$ 

160

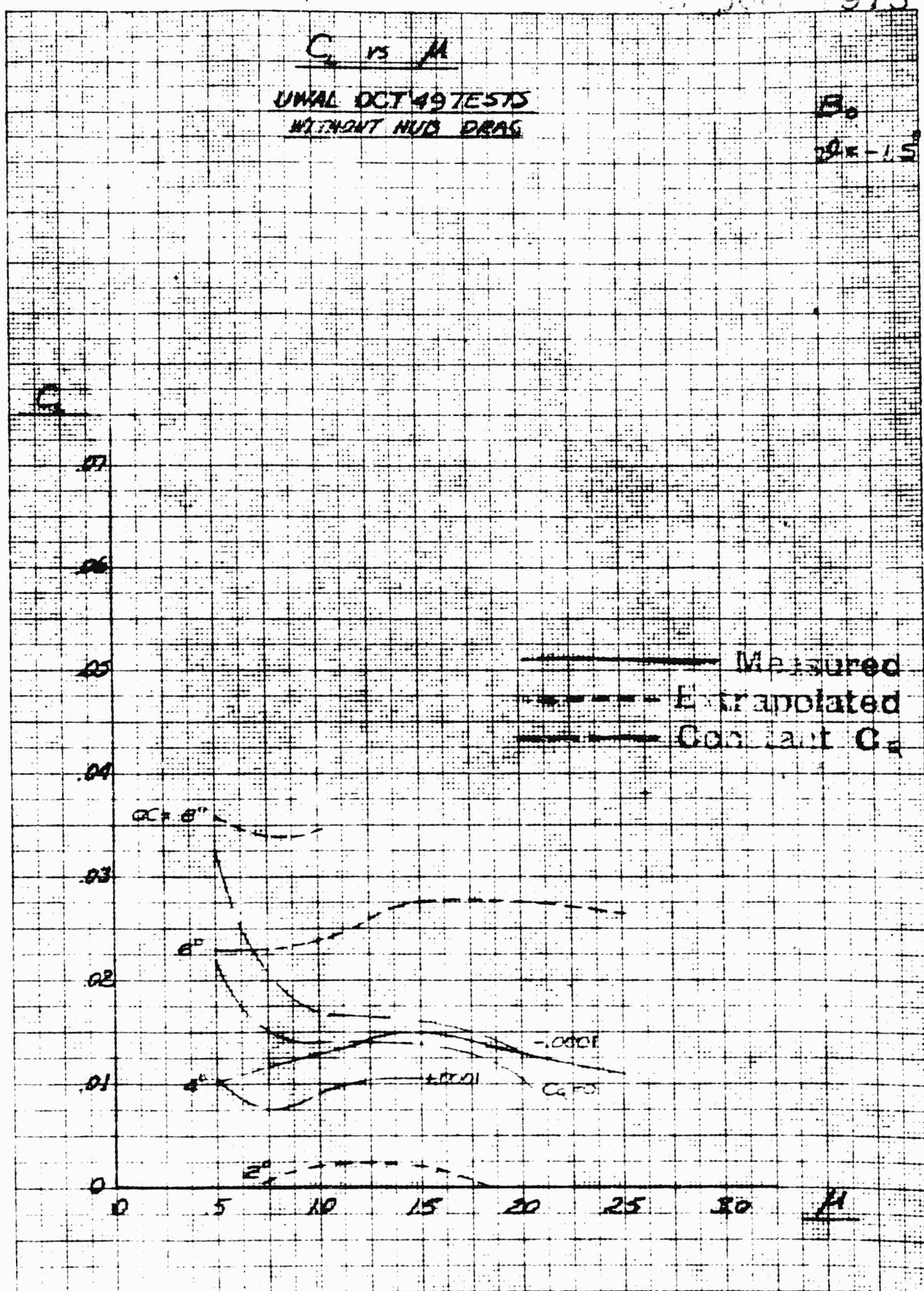
1975

C_L vs A

UNAL OCT 49 TESTS
WITHOUT HUB DRAG

B_0

$2\pi - 15^\circ$



KEUFFEL & ESSER CO.

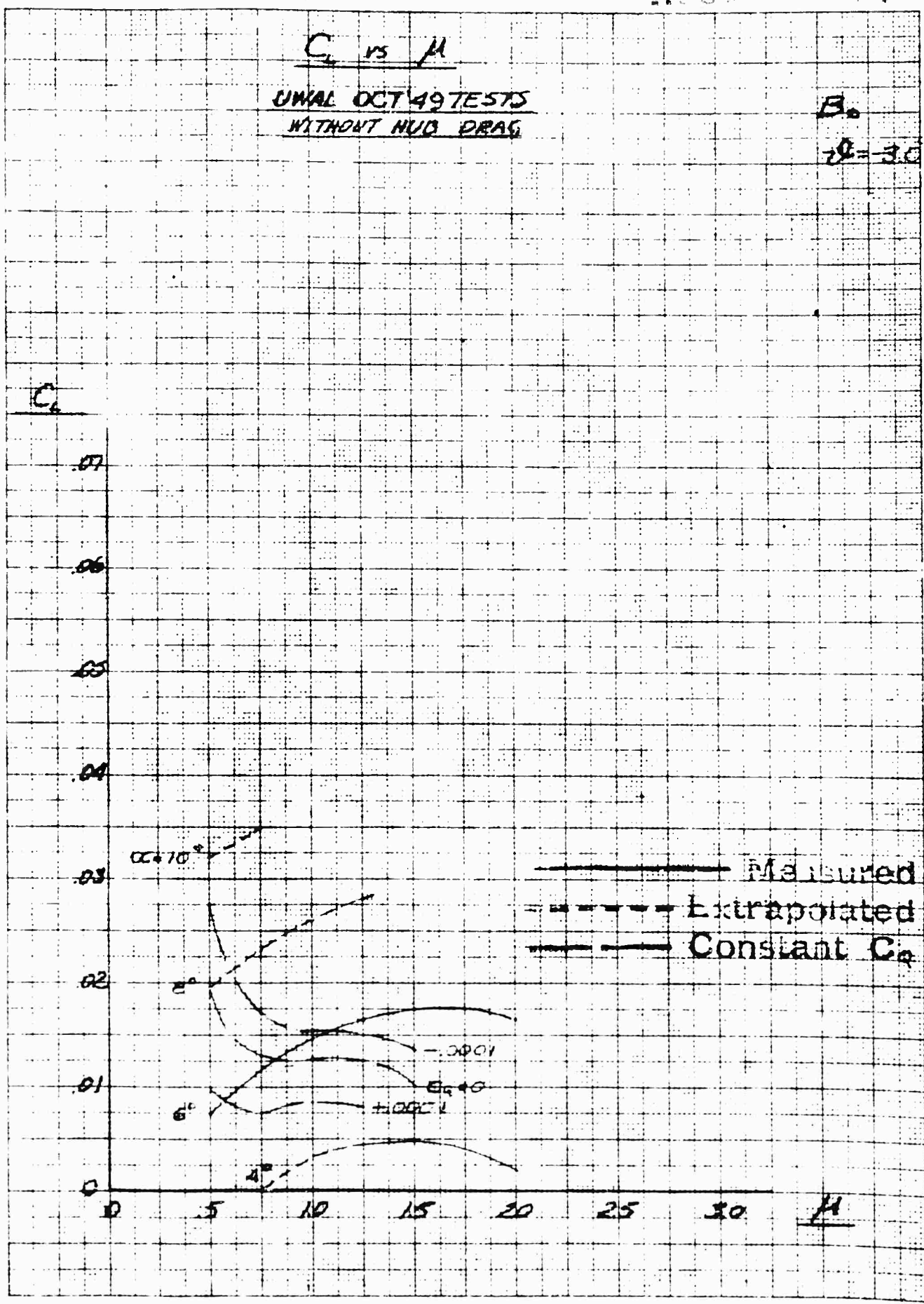
No. 359 14 Millimeters 5 mm lines, heavier 1 cm lines, heavier

C_L vs μ

UNAL OCT 49 TESTS
WITHOUT HUB DRAG

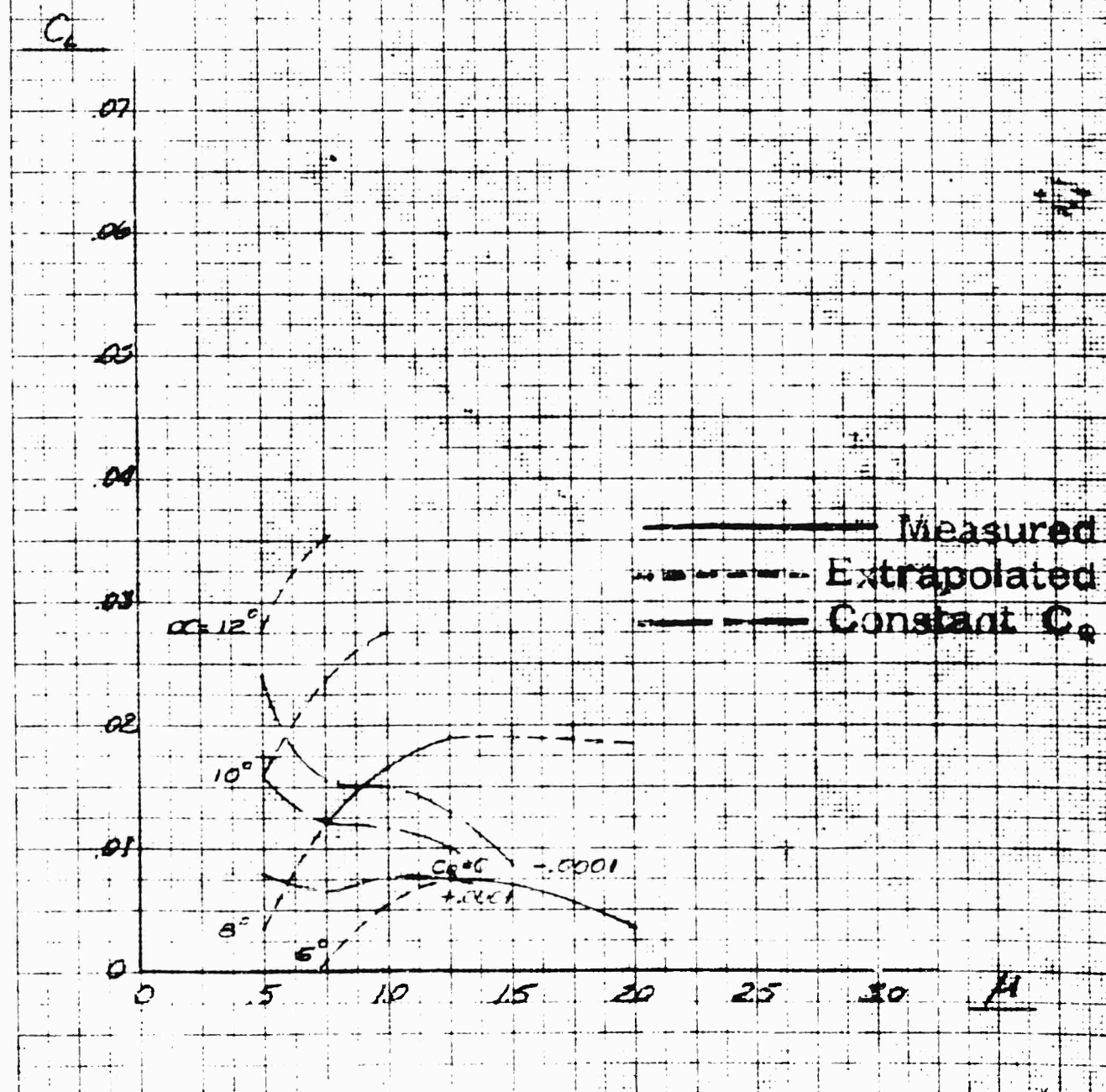
B.

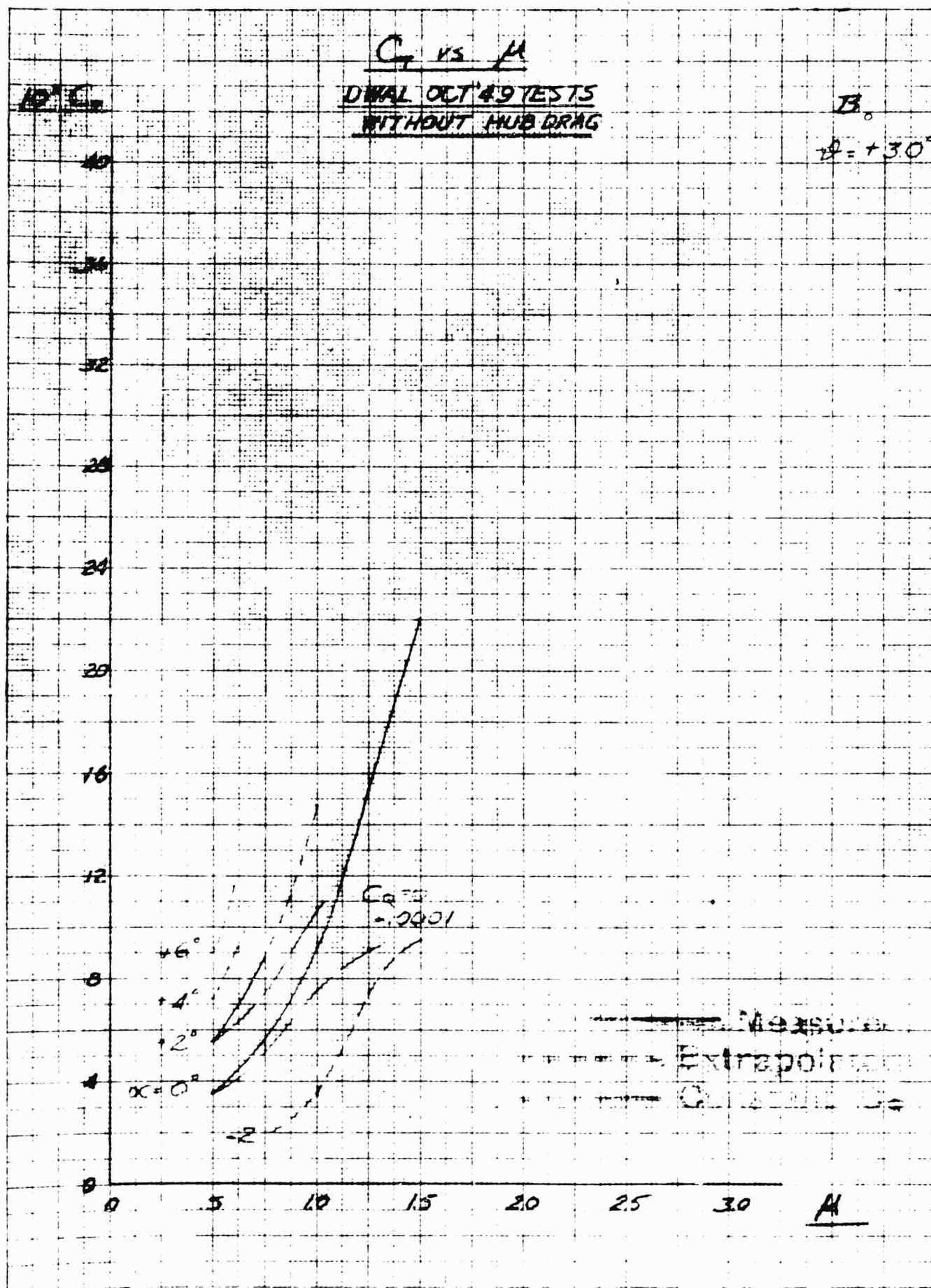
$\alpha = 30^\circ$



KEUPEL & EUGER CO

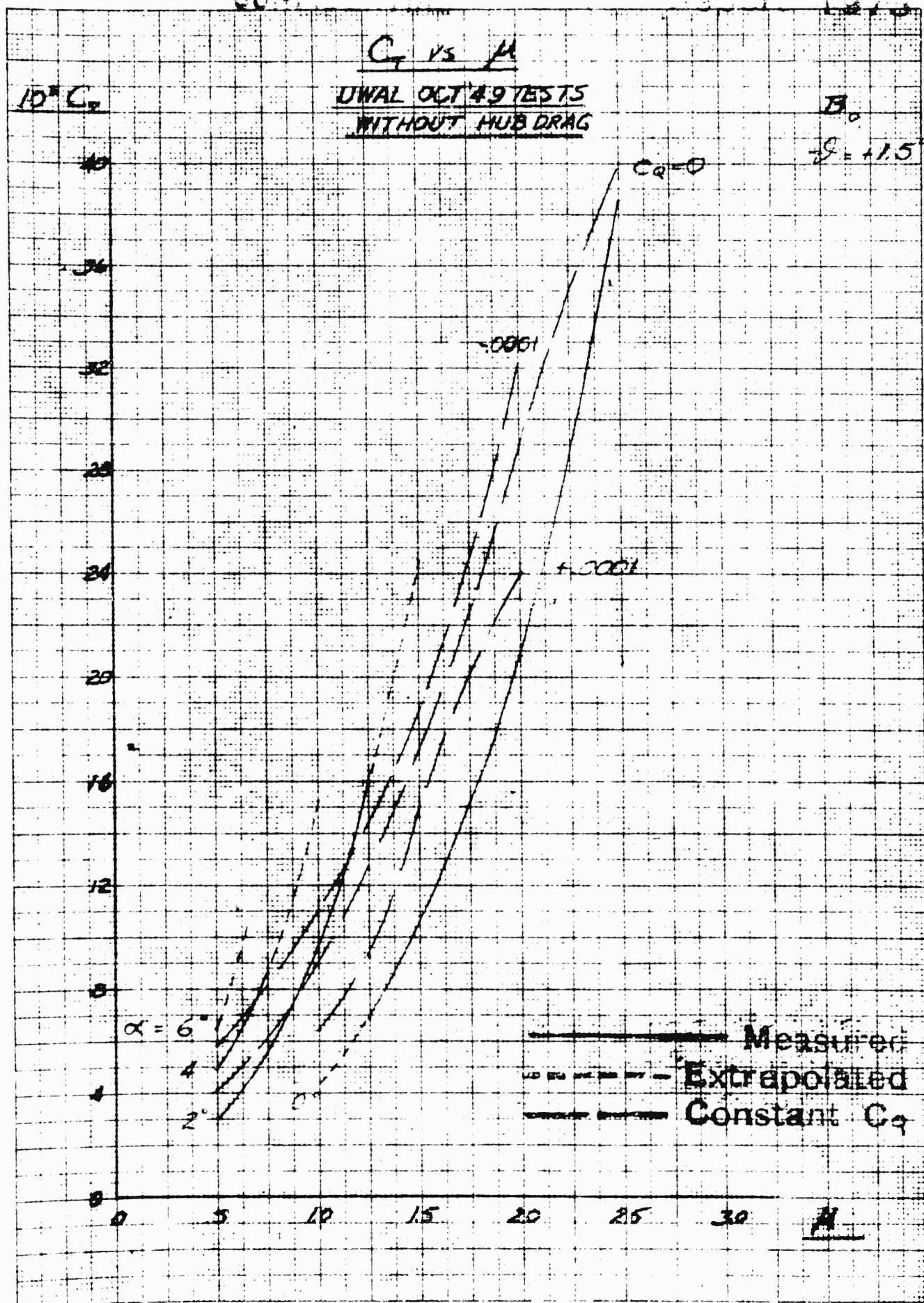
Fig. 1.1.1. Multiple Simultaneous Measurements of the Drag

C_d vs M UNAL OCT 49 TESTS
WITHOUT HUB DRAG B_0 $\theta = 4.5^\circ$ 

C_T vs μ DINAL OCT '49 TESTS
WITHOUT HUB DRAG β $\beta = +30^\circ$ 

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C_T vs μ

UWAL OCT 49 TESTS
WITHOUT HUB DRAG

β_0
 $\beta = 0^\circ$

$10^3 C_T$

40
36
32
28
24
20
16
12
8
4
0

-0.0001

+0.0001

$\alpha = 5^\circ$

6°

4°

2°

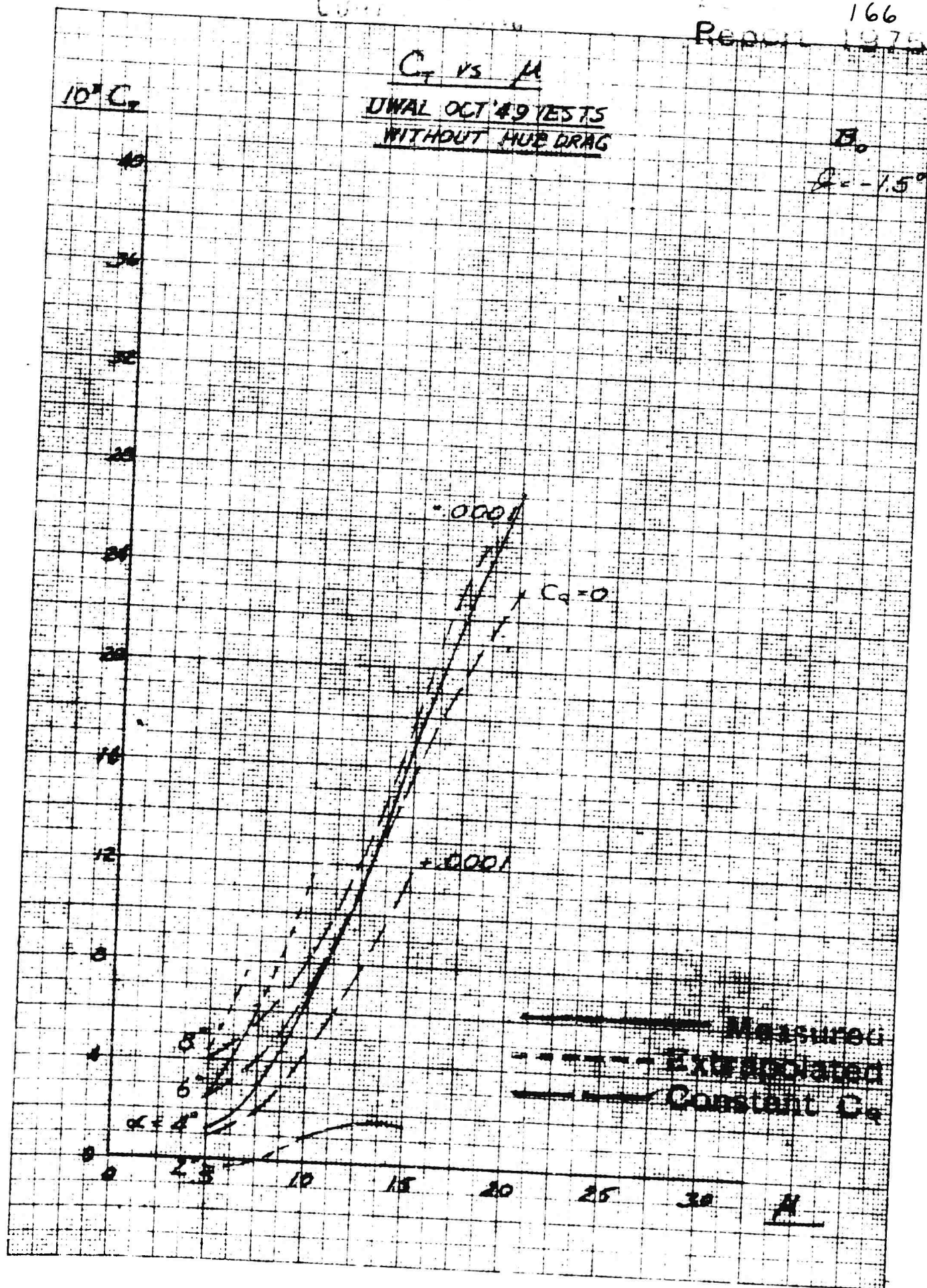
Measured
----- Extrapolated
Constant C_e

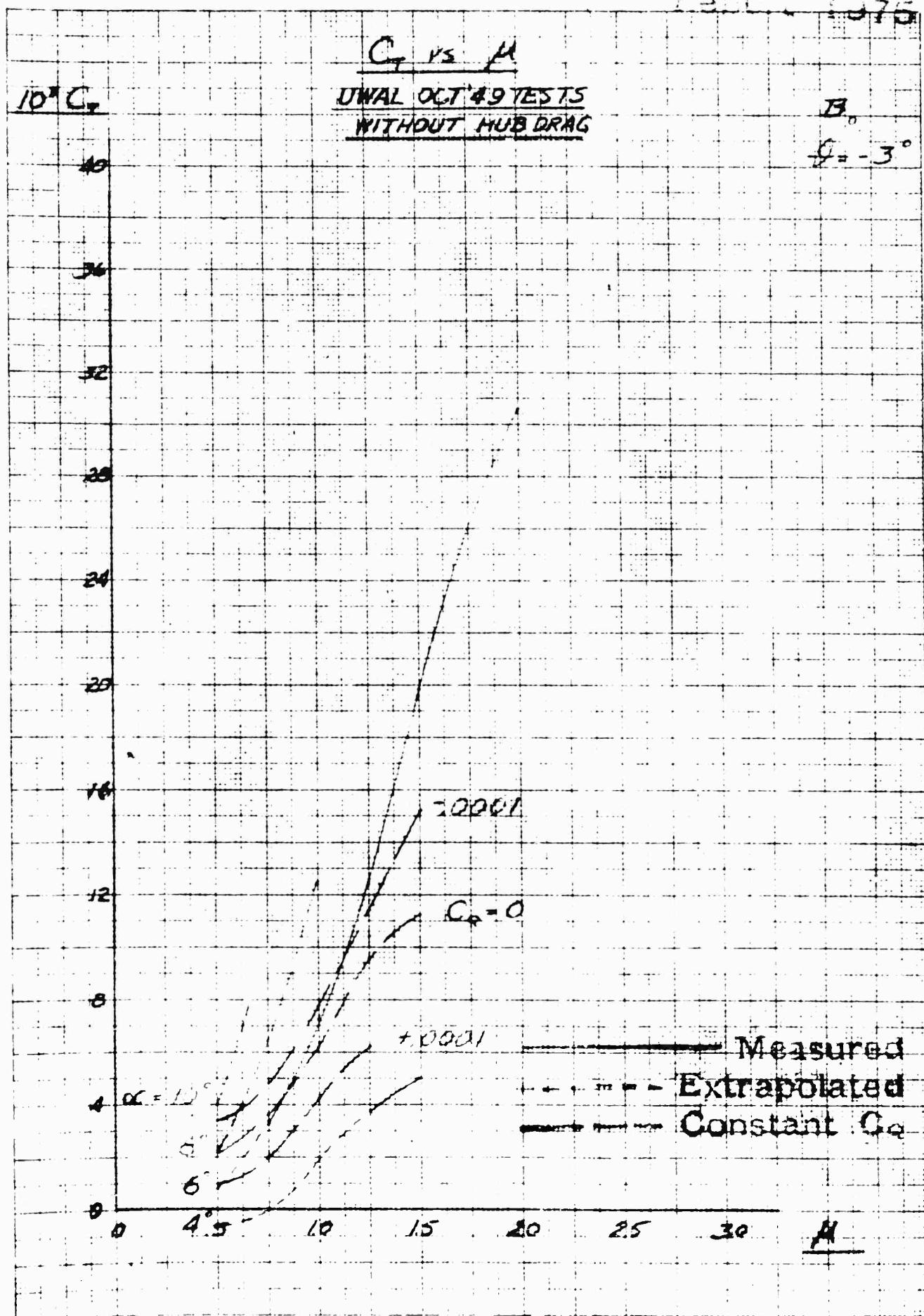
0 5 10 15 20 25 30 μ

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RCS
12-13-49

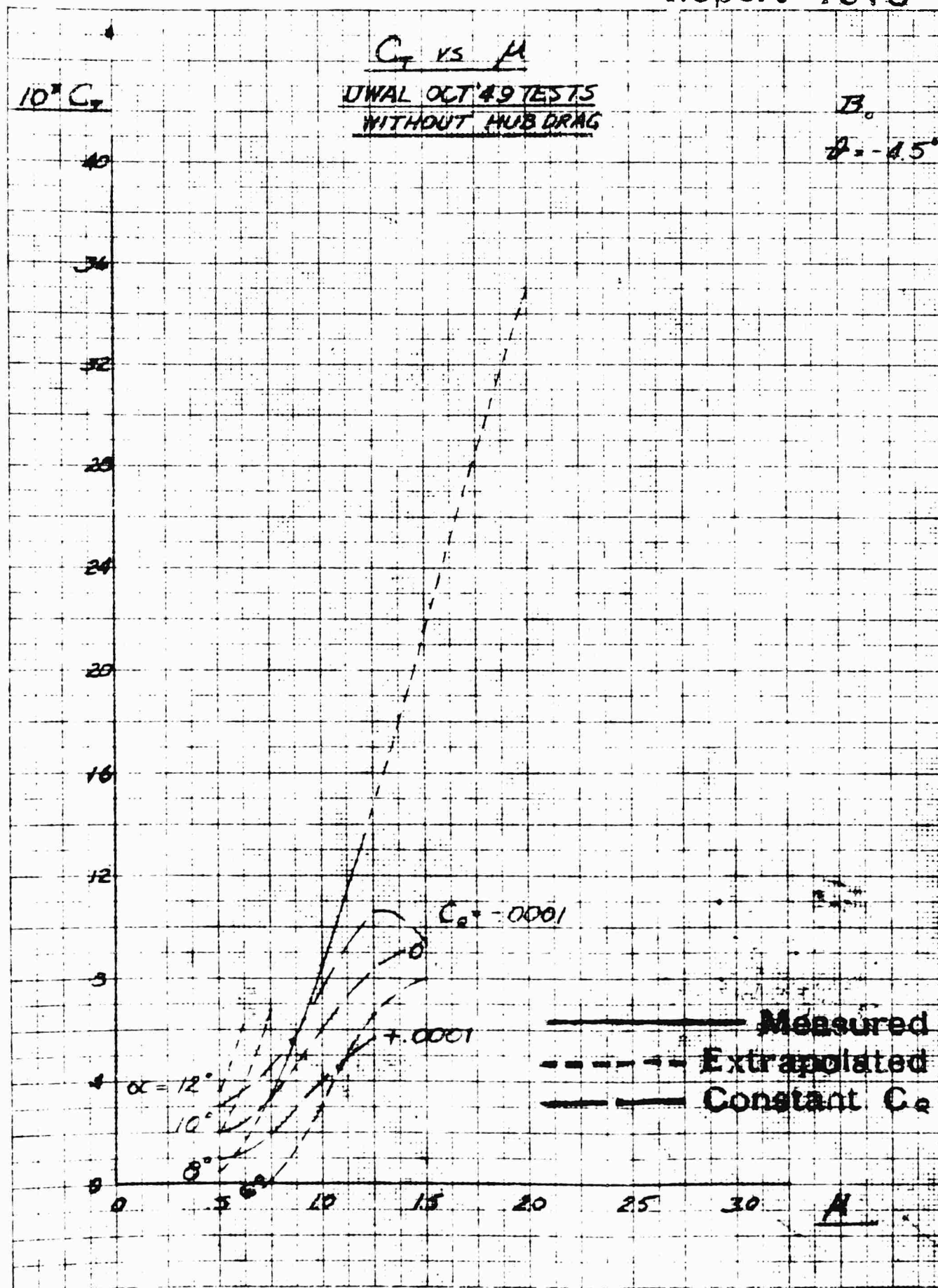
No. 359 1A Millimeters 5 mm lines 2.5 mm lines 0.5 mm lines 0.2 mm lines 0.1 mm lines





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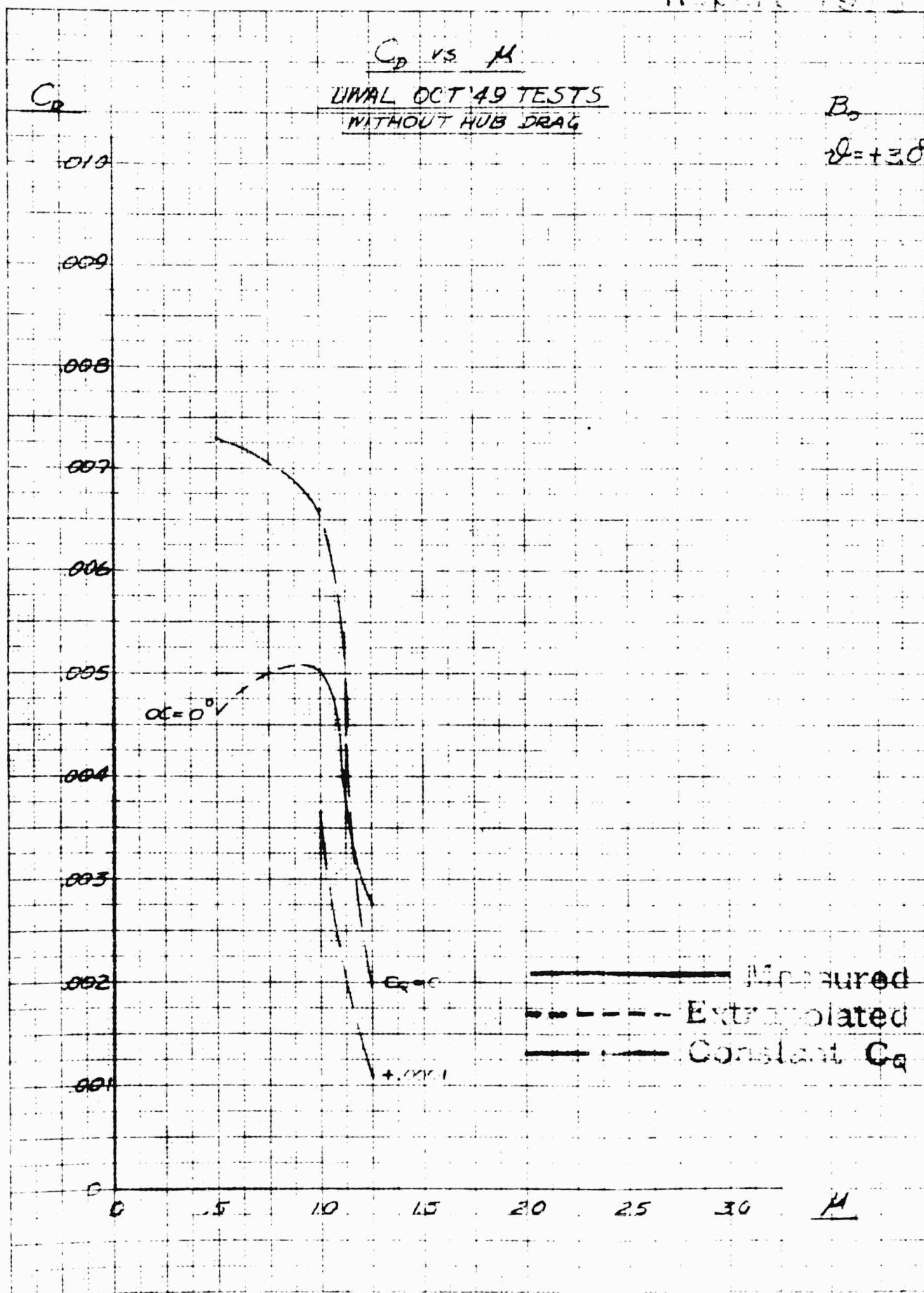
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Report 1975



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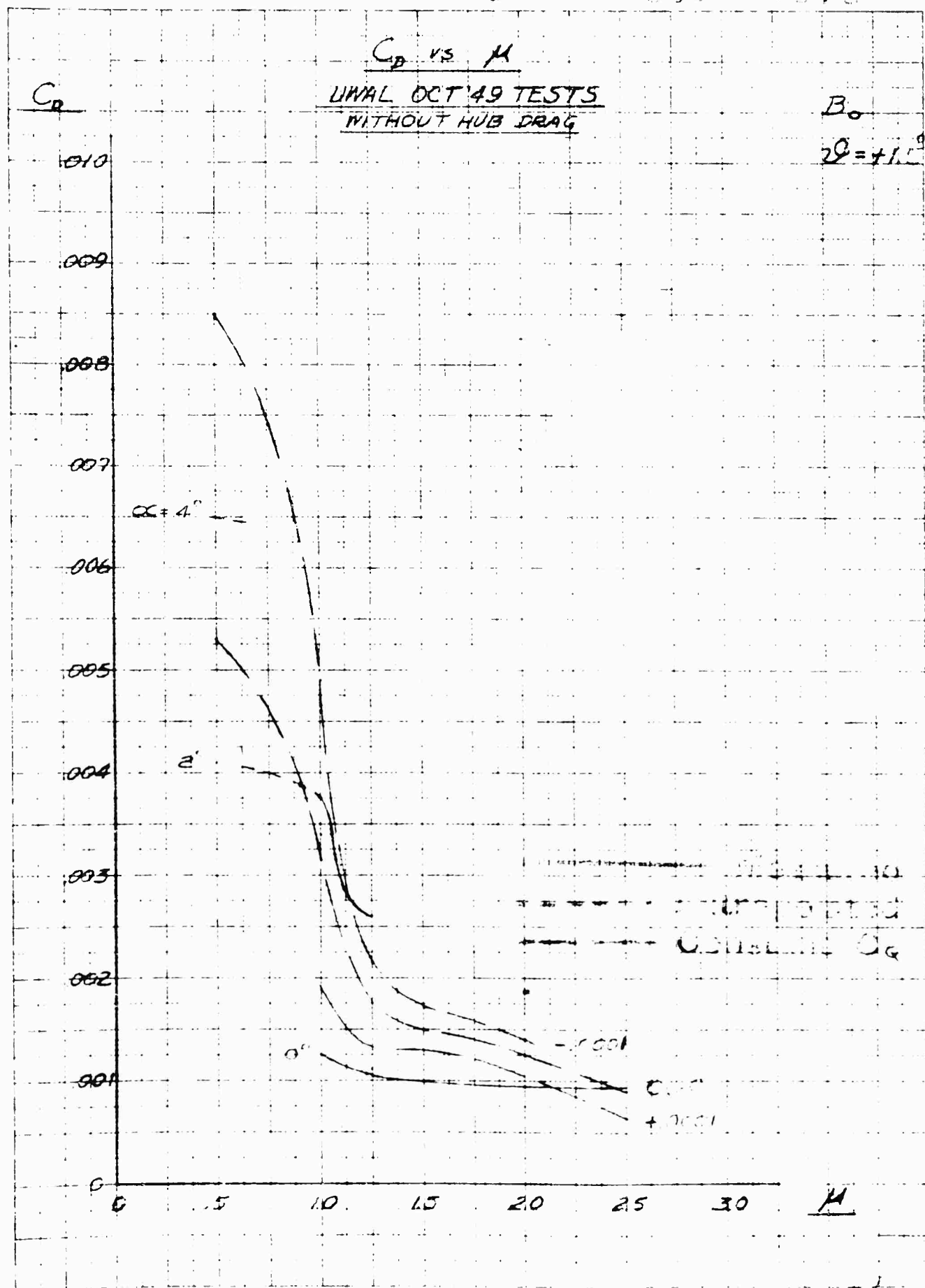
No. 359 11 Millimeters 5 mm lines, arcuated, cm lines heavy

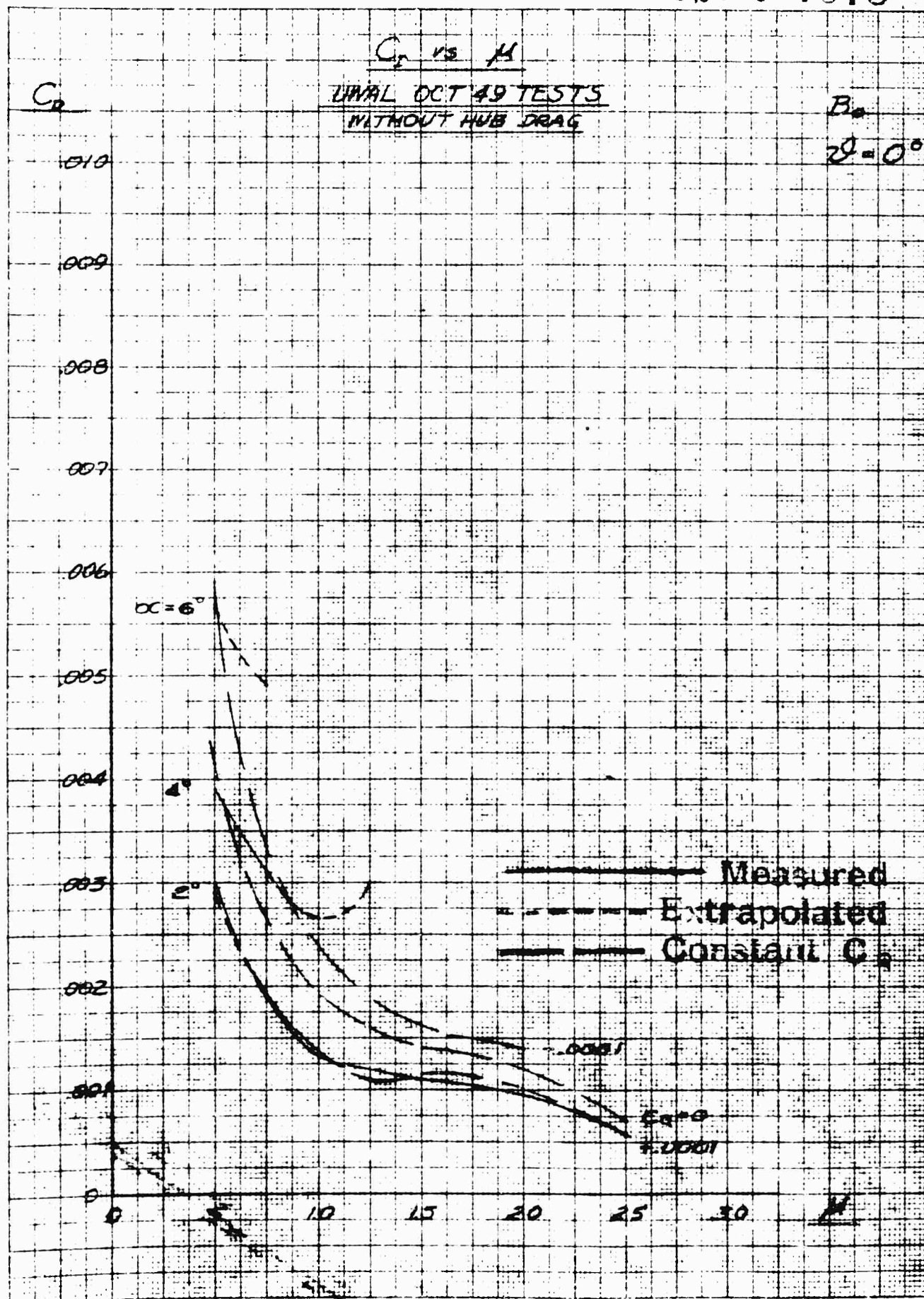
RCS
12-13-49



(112)

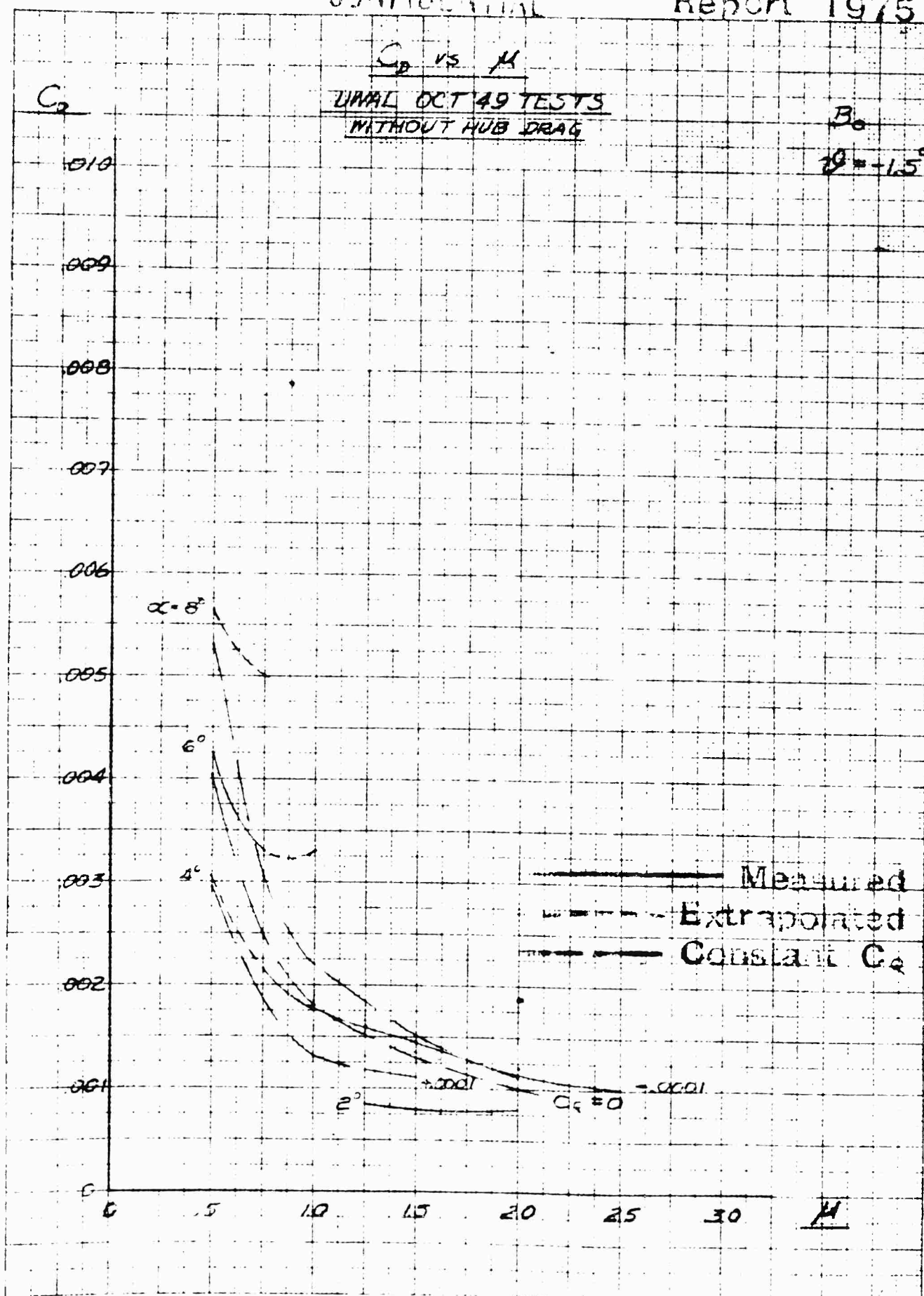
1000000 1973





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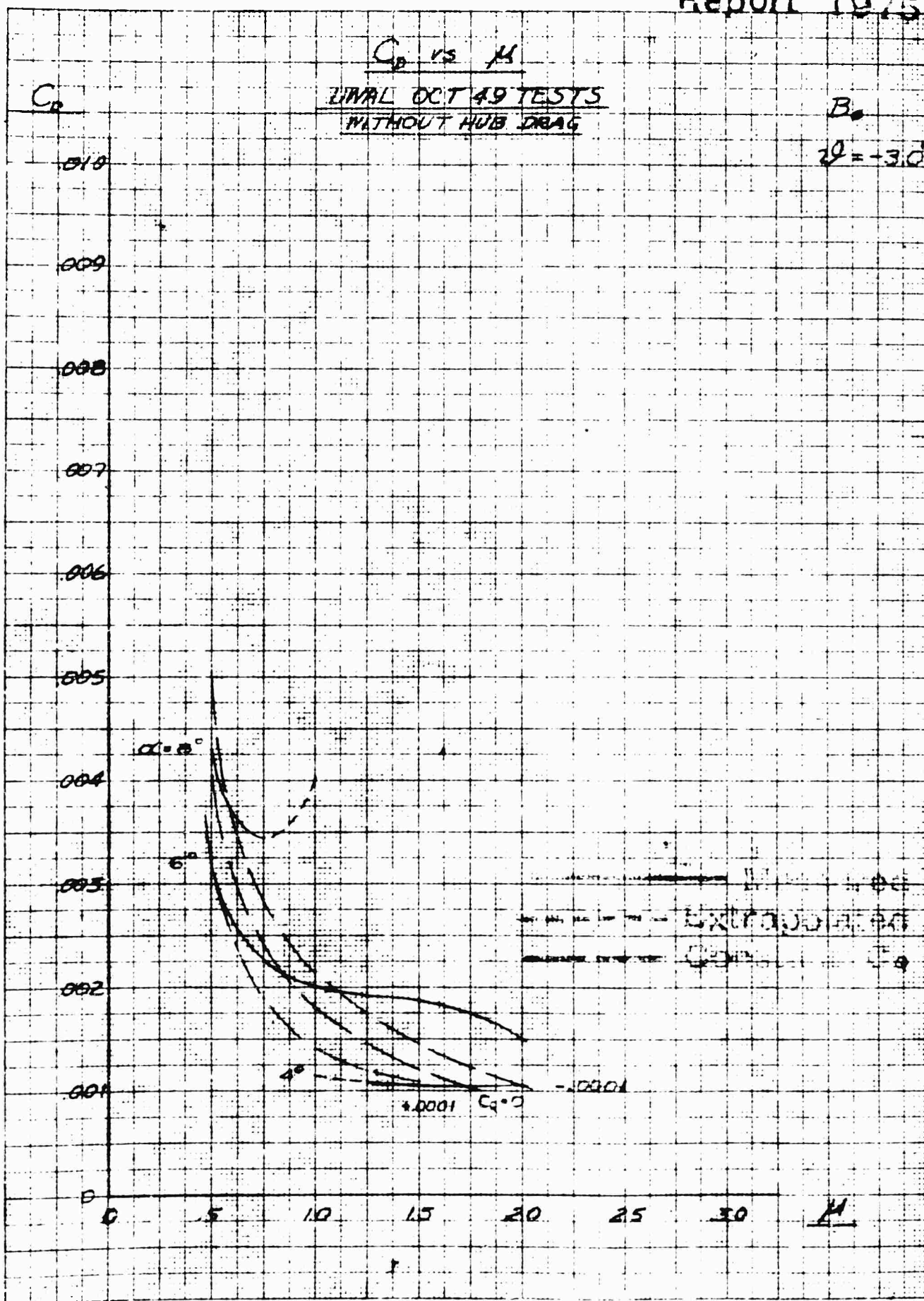
RECEIVED 1952-10-01

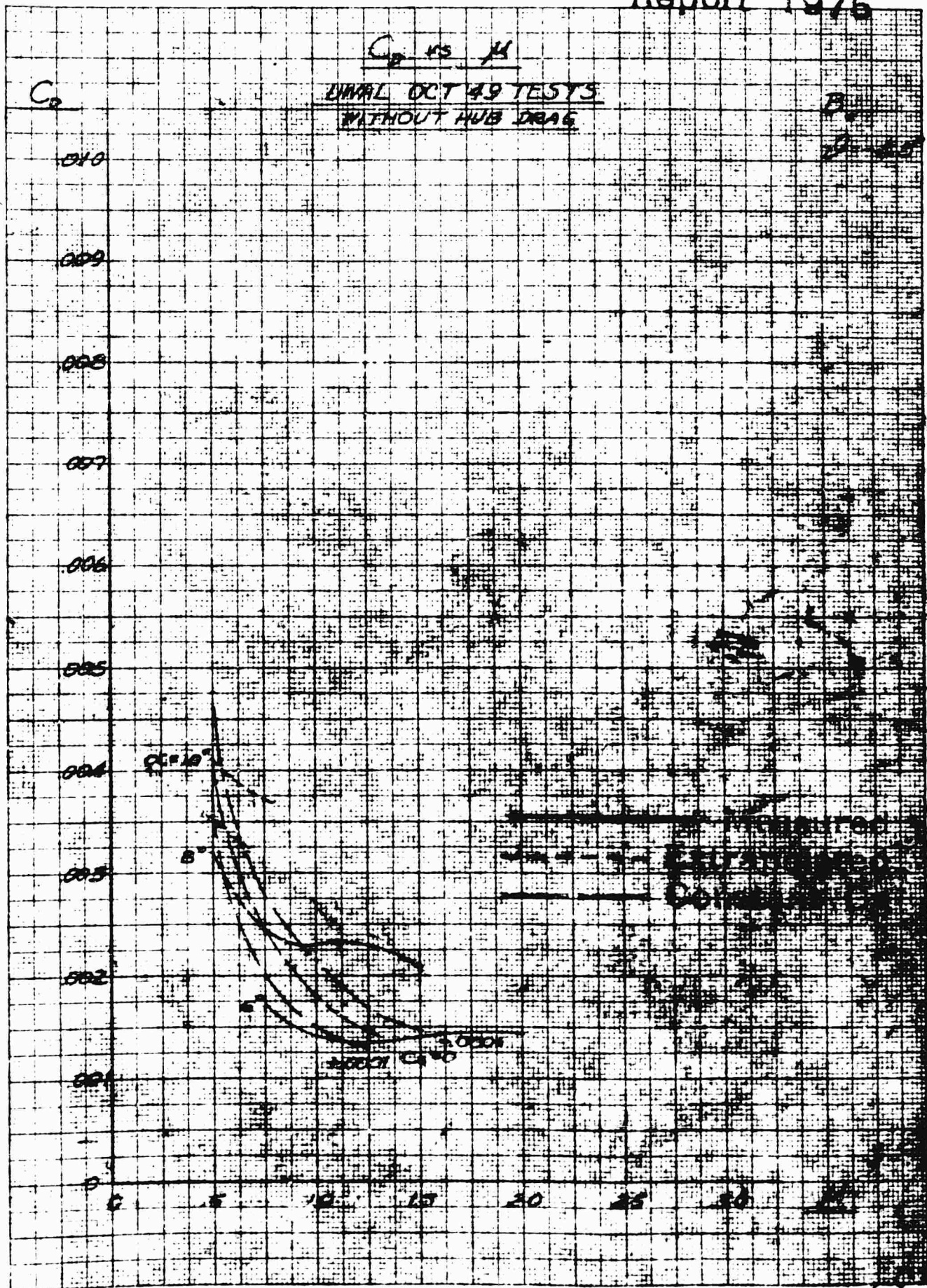
No. 1014 - Miscellaneous - 10-1-52 - 10-1-52

184
10-1-52

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No 359 14 Millimeters, 5 mm lines, acented, cm lines heavy

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12-13-47

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L/D vs H

UNAL OCT 49 TESTS
WITHOUT HUB DRAG

B_0

$\theta = 4.5^\circ$

L/D

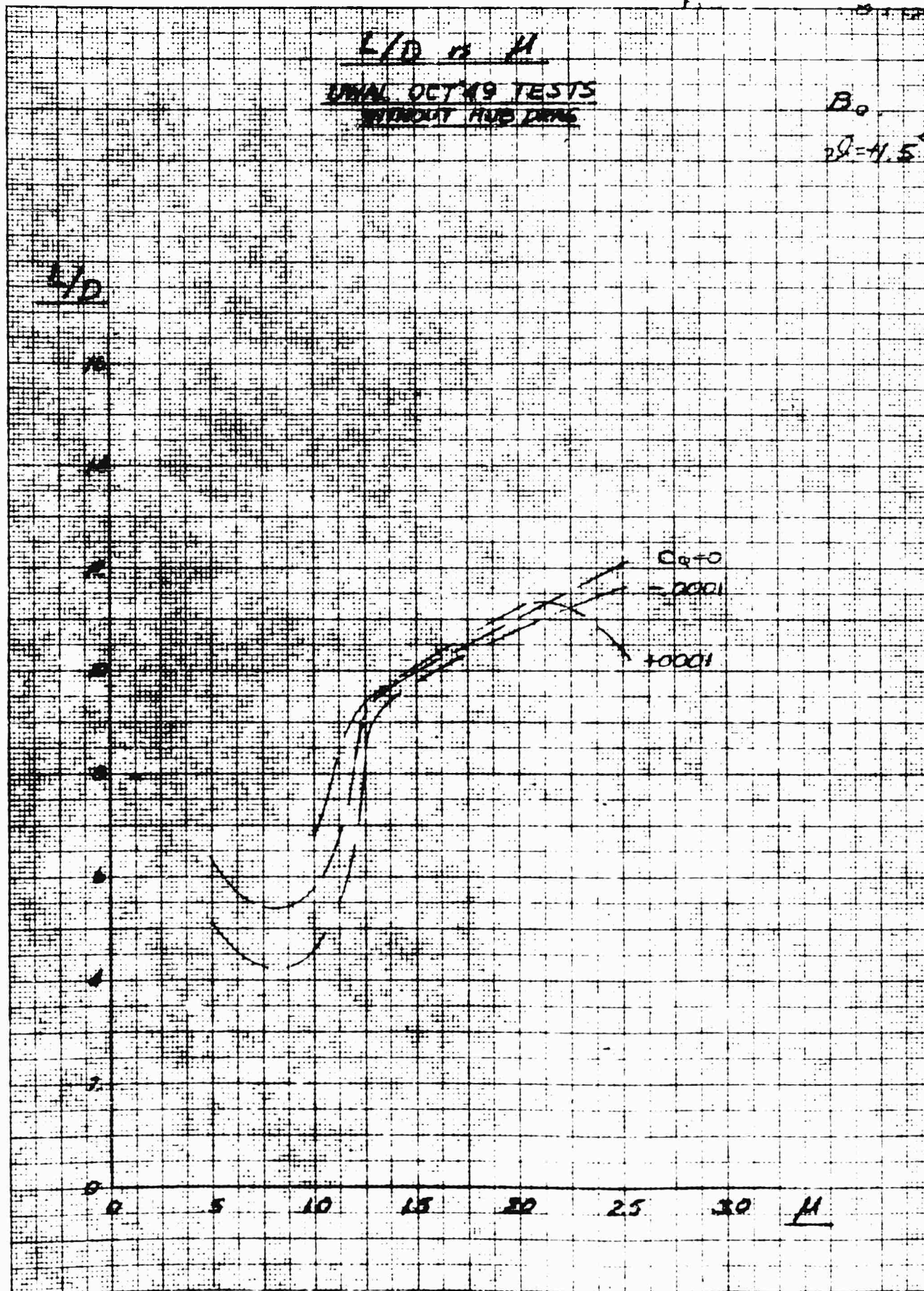
C_{q+0}

-0.0001

$+0.0001$

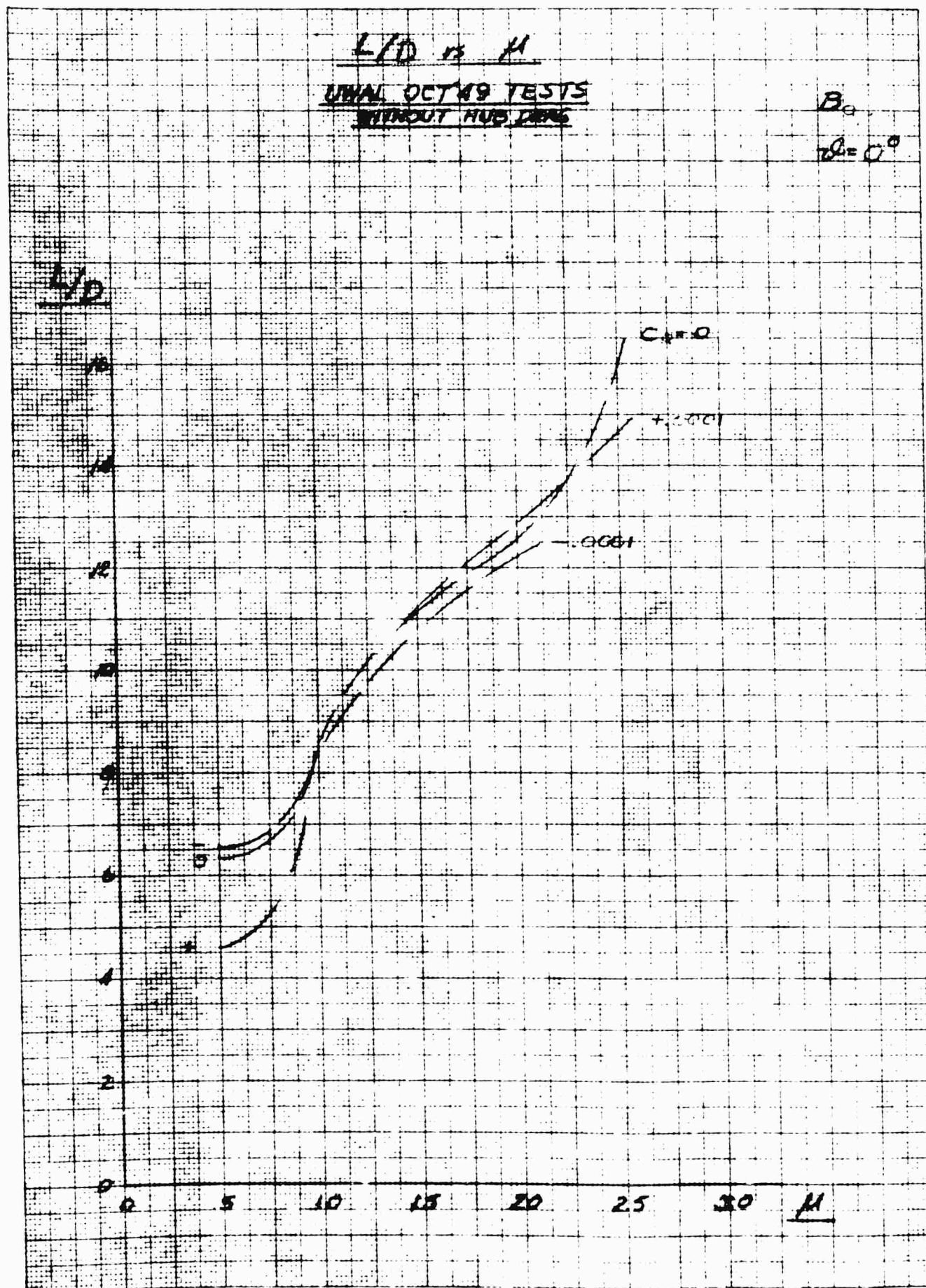
KEUFFEL & ESSER CO.

No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy



L/D vs M
UNAL OCT 49 TESTS
WITHOUT HUB DRAG

B_0
 $\alpha = 0^\circ$



L/D H H

FINAL OCT 18 TESTS
WITHOUT THE JUNE

B.

10-15

L/D

10

10

0.001

0.010

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202

KEUFFEL & ESSER CO.

No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

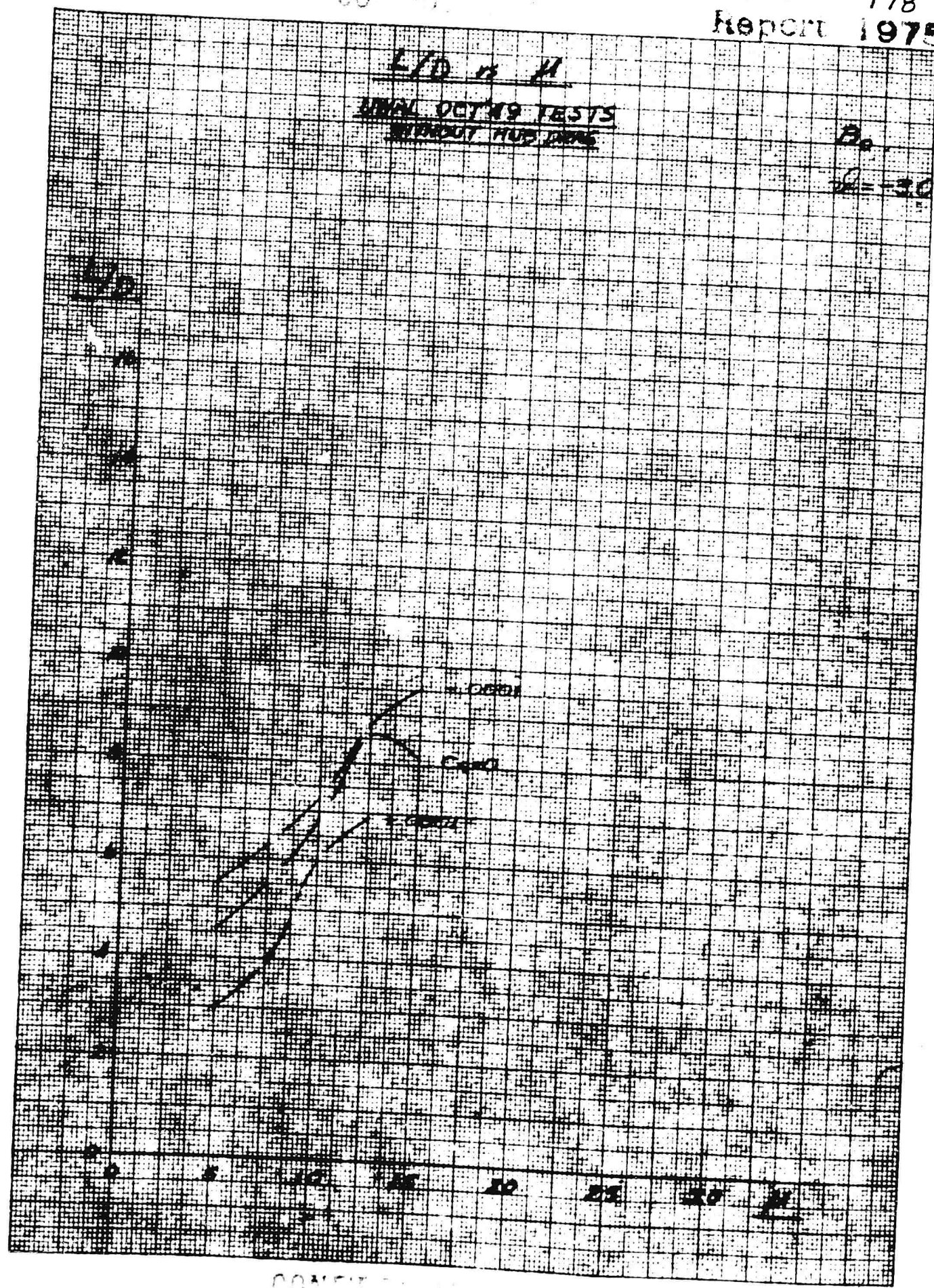
001 10

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1975

L/D n H

UNAL OCT 19 TESTS
WITHOUT HUB DRG

B₀
Q = -30°



KEUFFEL & ESSER CO.

No. 359 14. 5 mm lines centered, cm lines heavy

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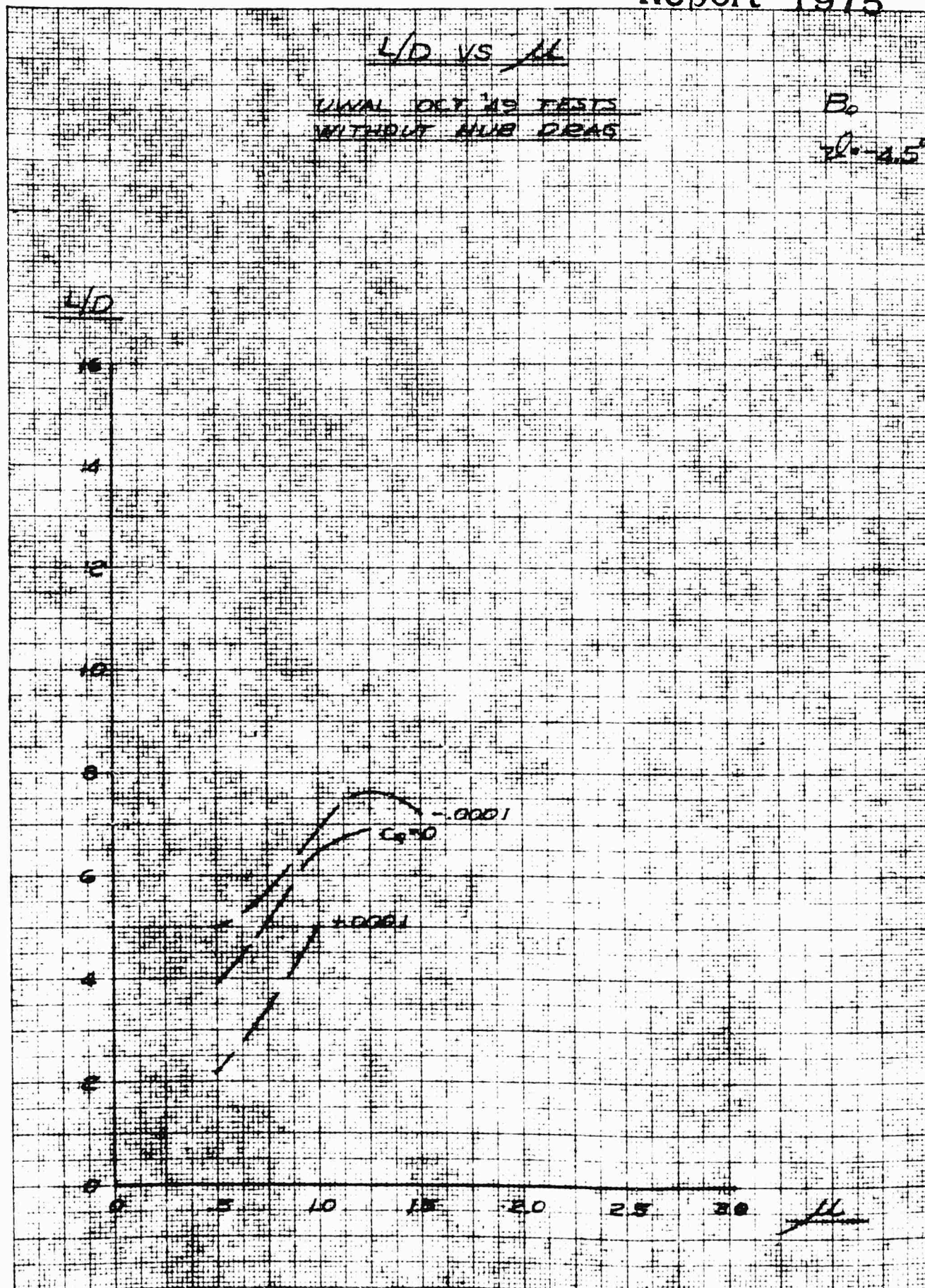
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L/D VS μ

UNVAL OCT '49 TESTS
WITHOUT HUB DRAG

B_0
 $\theta = 45^\circ$



KEUFFEL & ESSER CO.

No 55-14. Millimeters, 5 mm lines acented, cm lines heavy.

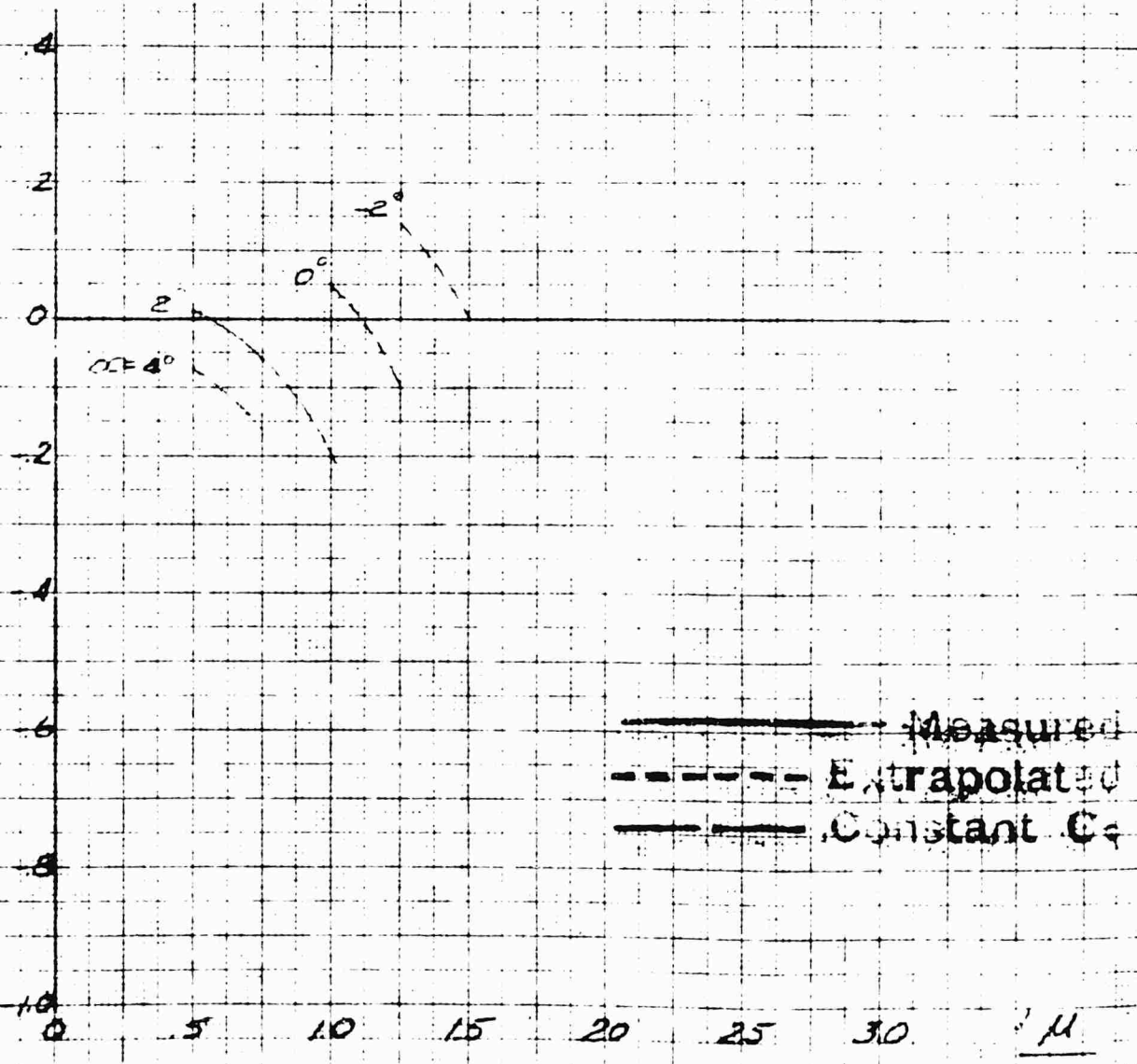
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118 180
 Re 1075

C_a vs μ
 UWAL OCT 49 TESTS
 WITHOUT HUB DRAG

B_0
 $\alpha = +3.0^\circ$

$10^3 C_a$



WUOTEC & FOSBERG

No. 319-13 Millimeters, 5 millimeters are entered. Centimeters in inches

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Report 1875

C_d vs μ

UWAL OCT 49 TESTS
WITHOUT HUB DRAG

B_0

$\alpha = +1.5^\circ$

$10^3 C_d$

4

2

0

-2

-4

-6

-8

-10

0

5

10

15

20

25

30

μ

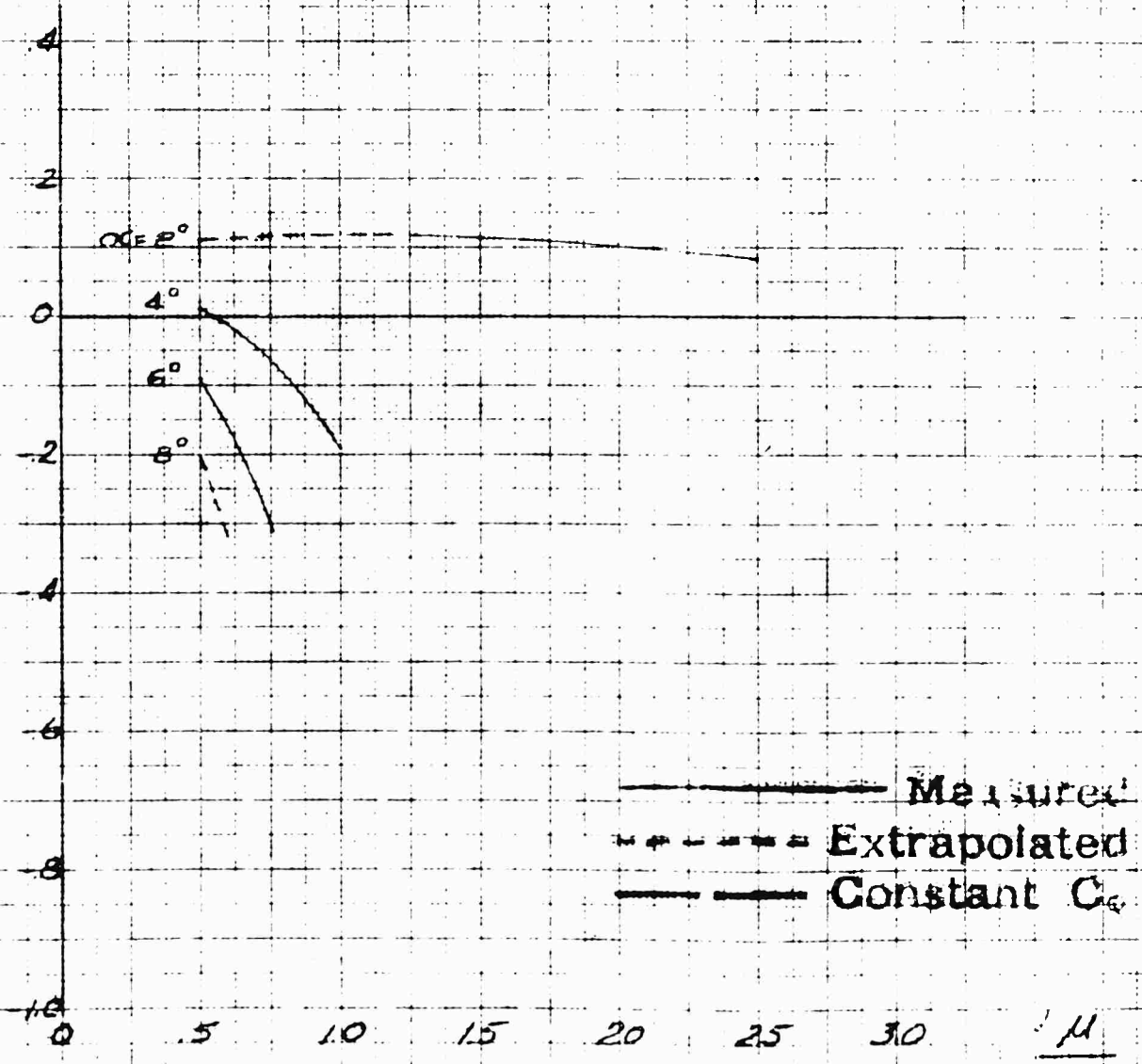
Measured
Extrapolated
Constant C_d

18K
Revised 1975

C_d vs μ
UWAL OCT 49 TESTS
WITHOUT HUB DRAG

B_0
 $\alpha = 0^\circ$

$10^3 C_d$



KEUTEL & JONES CO.

UWAL OCT 49 TESTS WITHOUT HUB DRAG

C_a vs μ

UWAL OCT 49 TESTS
WITHOUT HUB DRAG

B_0

$\beta = -1.5^\circ$

$10^3 C_a$

4

2

0

-2

-4

-6

-8

-10

0

5

10

15

20

25

30

μ

Measured
Extrapolated
Constant C_a

NEUFEL & ESSER CO

No. 359 14. Millimeters, 5 mm lines accented, on lines heavy

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1878

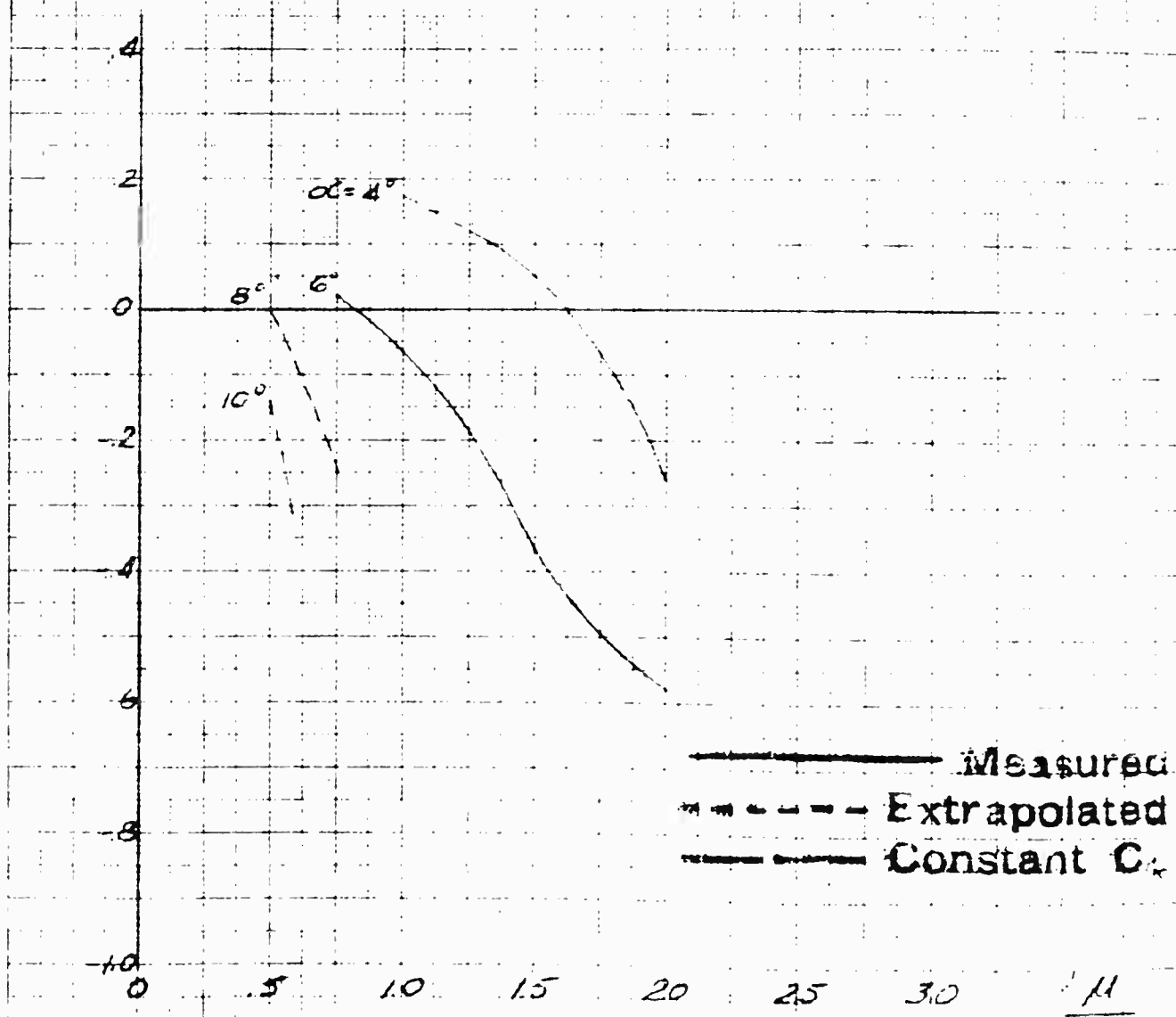
C_a vs μ

UWAL OCT 49 TESTS
WITHOUT HUB DRAG

B_0

$\alpha = -30^\circ$

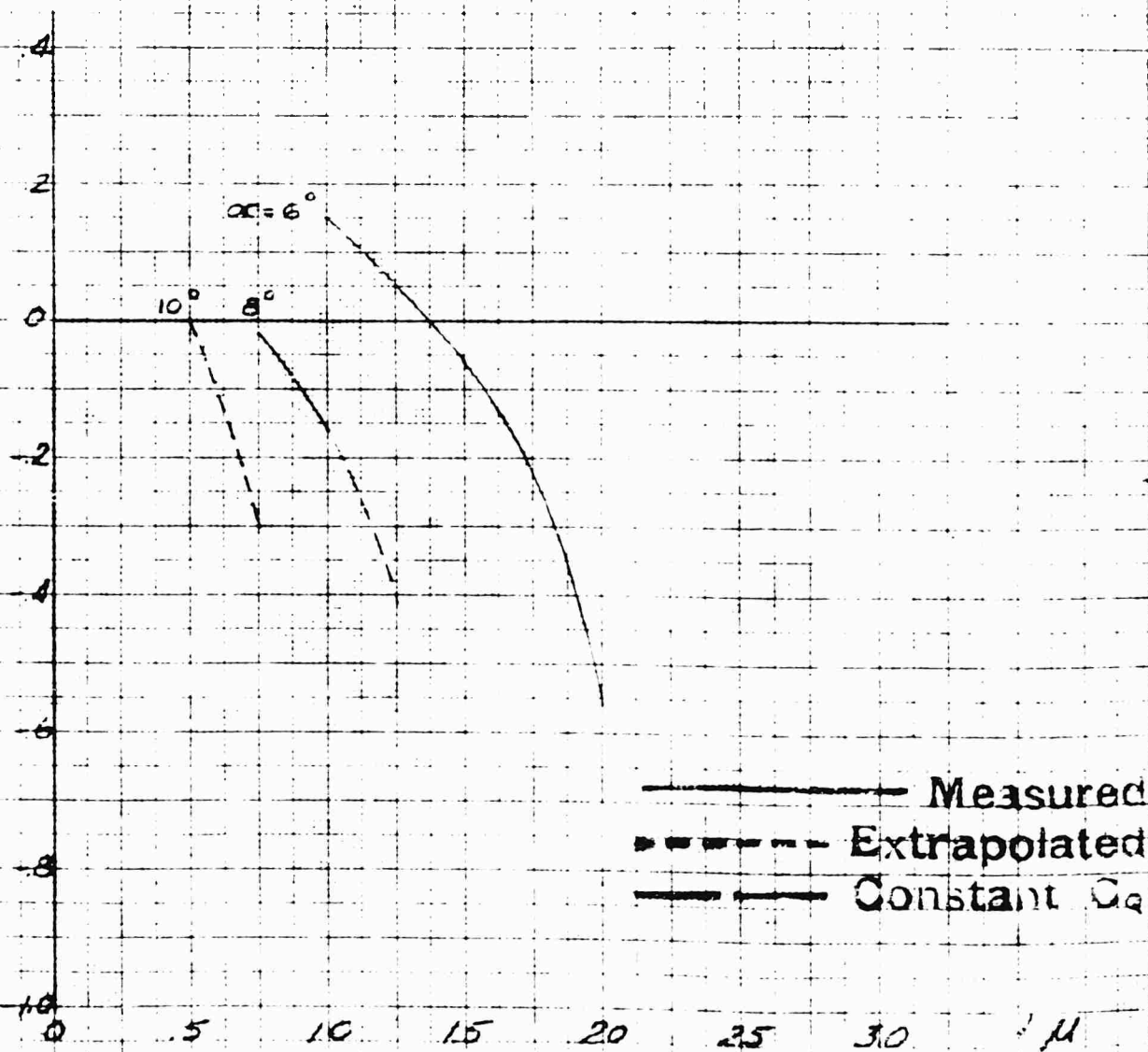
$10^3 C_a$

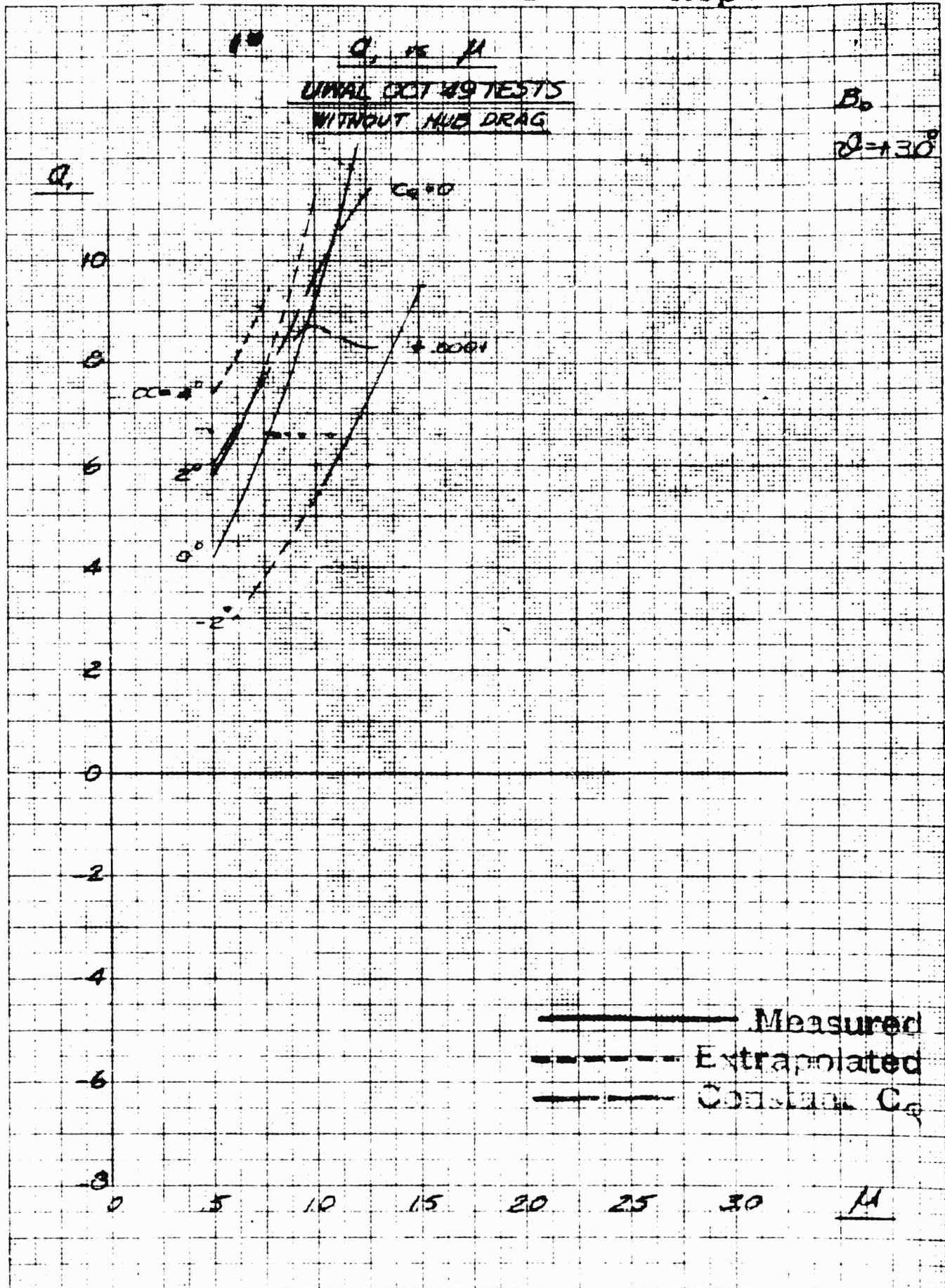


C_D vs. μ
UWAL OCT'49 TESTS
WITHOUT HUB DRAG

B_o
 $\alpha = -4.5^\circ$

$10^3 C_D$

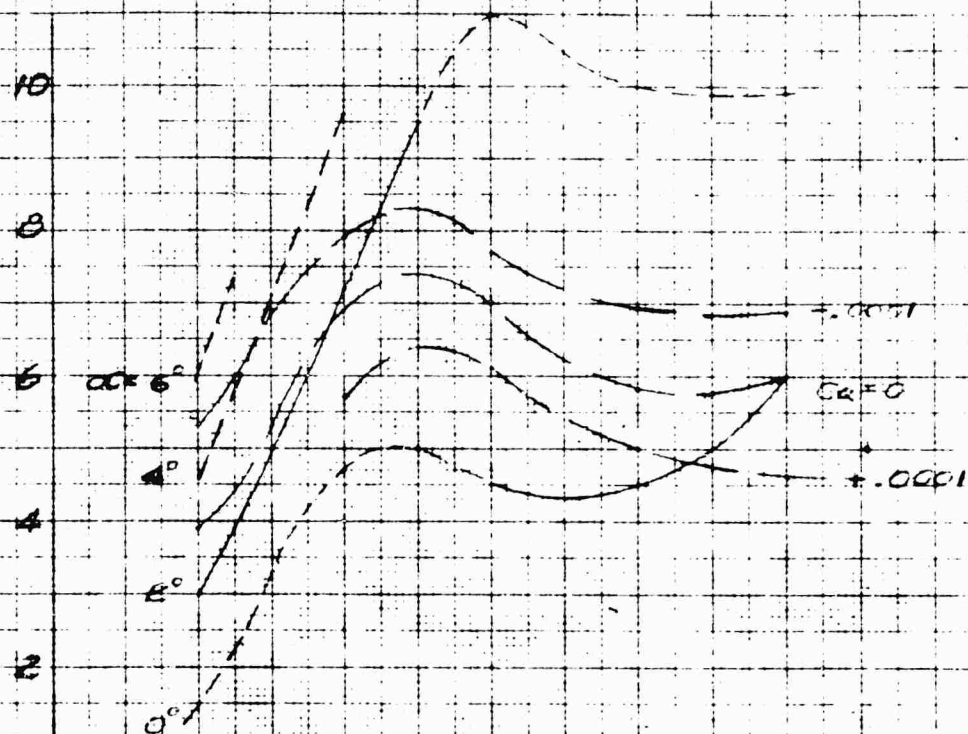




C_L vs μ
UNAL OCT 49 TESTS
WITHOUT HUB DRAG

B_p
 $\theta = +1.5^\circ$

C_L



— Measured
 - - - Extrapolated
 — Constant C_L

0 5 10 15 20 25 30 μ

$Q, \text{ vs } \mu$
UWAL OCT 49 TESTS
WITHOUT HUB DRAG

B_0

$\phi = 0^\circ$

Q

10

8

6

4

2

0

-2

-4

-6

-8

$\alpha = 6^\circ$

0°

-0.001

$C_d = 0$

+0.001

Measured
 Extrapolated
 Constant C_d

0

5

10

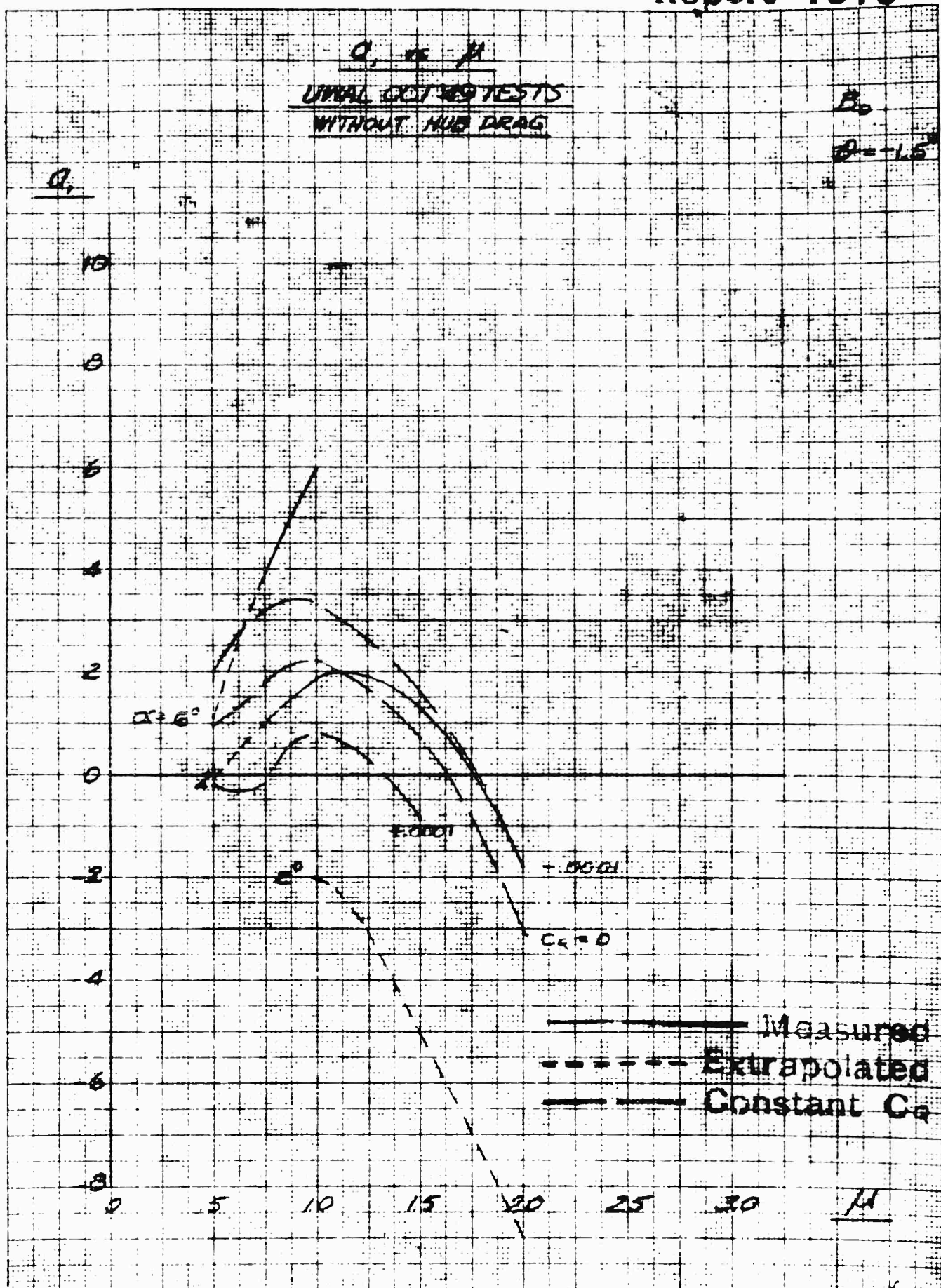
15

20

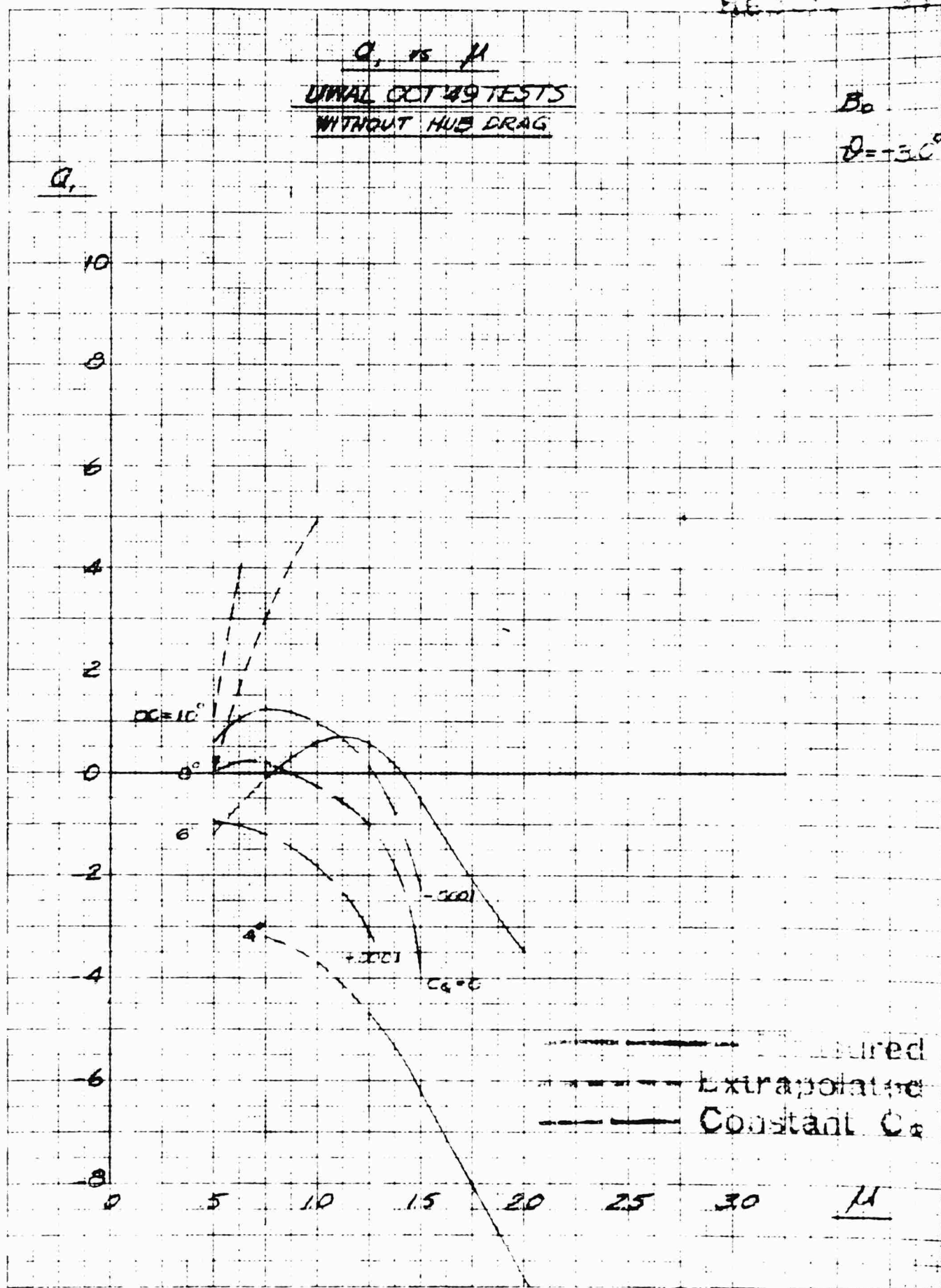
25

30

μ



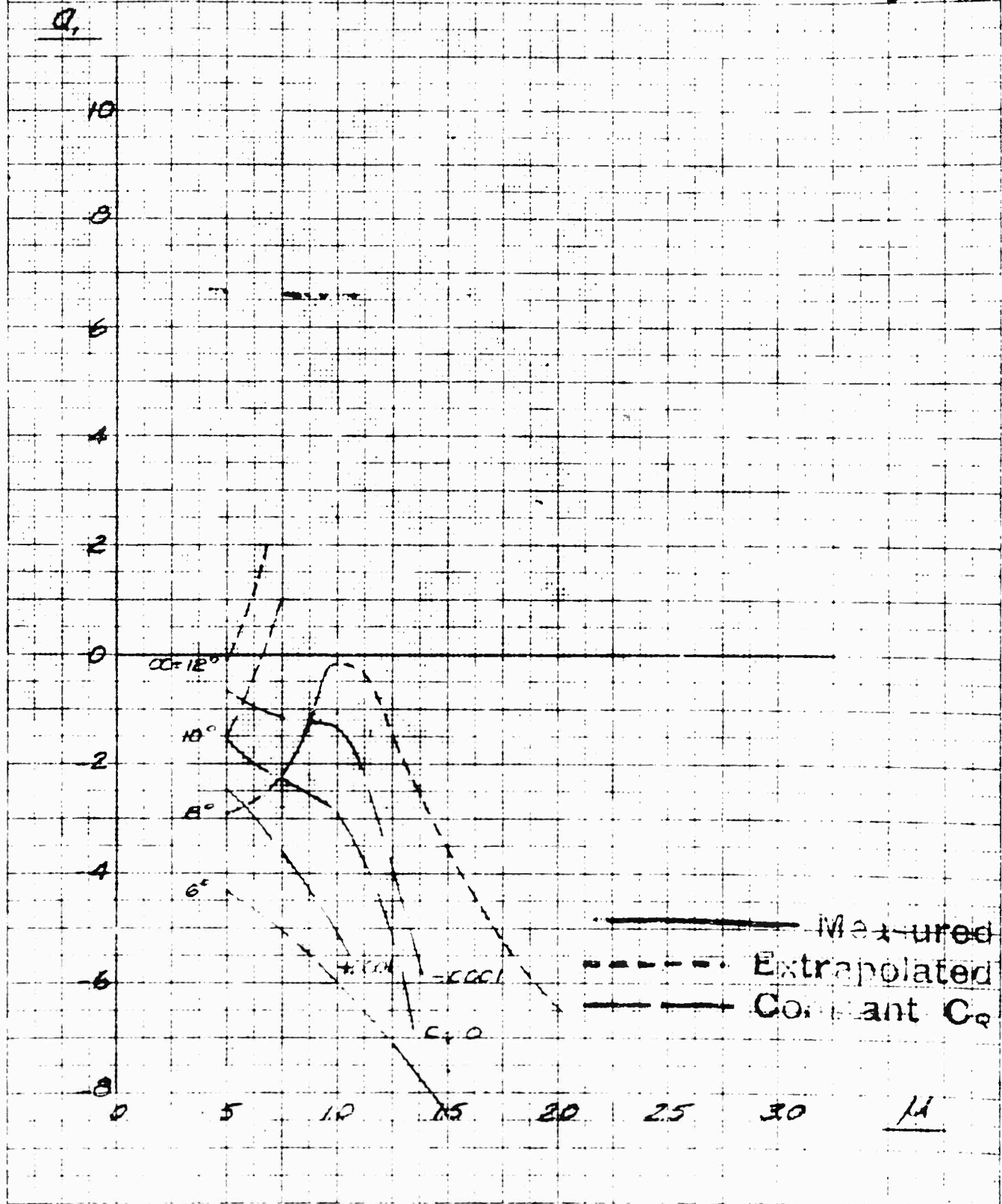
5-2-74
17 17 00



Q, vs μ
UNVAL OCT 49 TESTS
WITHOUT HUB DRAG

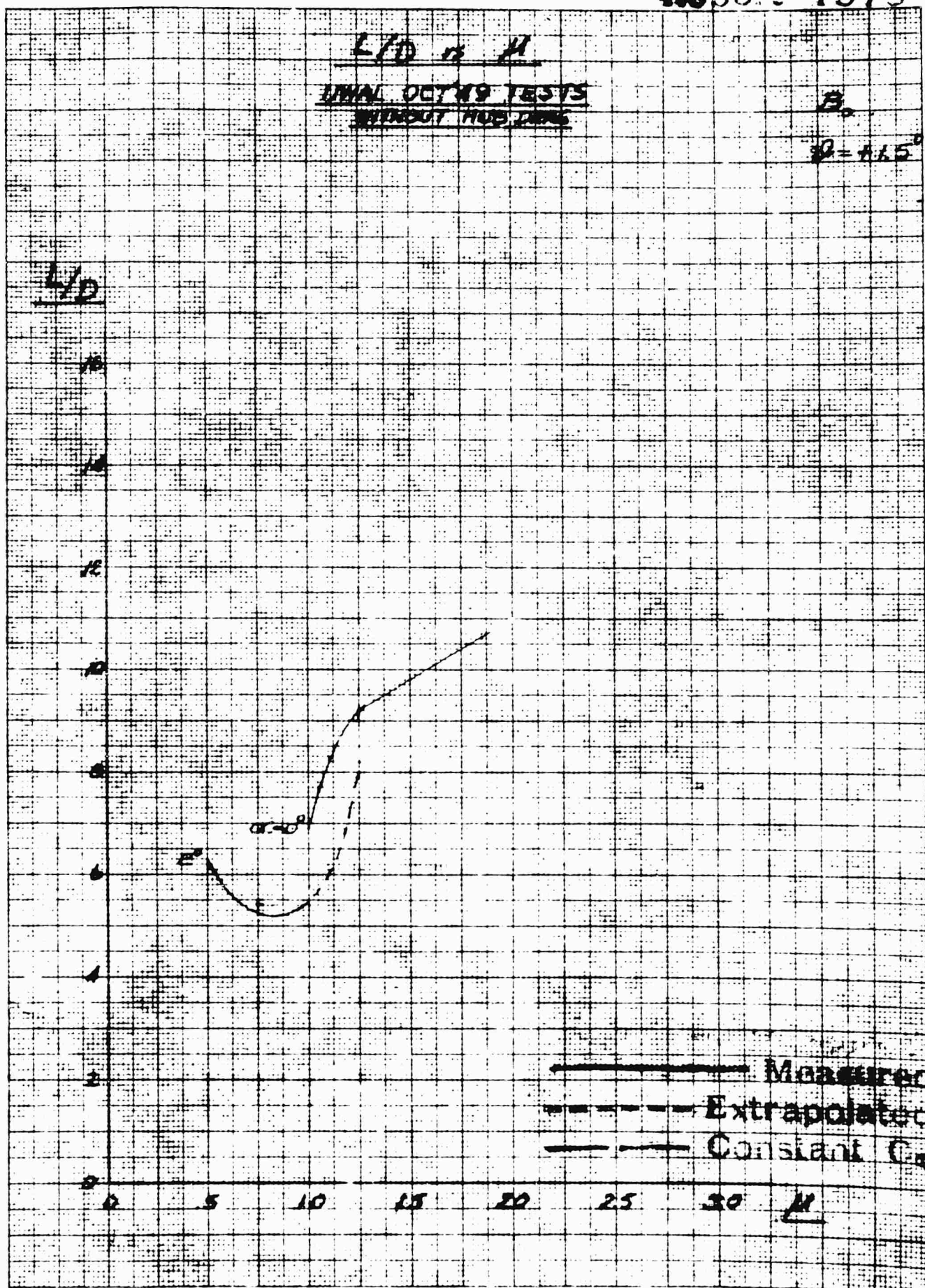
B_0

$\phi = -4.5^\circ$



L/D vs H
UNAL OCT 19 TESTS
WITHOUT HUB DRAG

$\beta = +1.5^\circ$



L/D vs μ
UNAL OCT 19 TESTS
WITHOUT HUB DRAG

 B_0 $\alpha = 0^\circ$ L/D

16

14

12

10

8

6

4

2

0

 $\alpha = 4^\circ$

————— Measured
 - - - - - Extrapolated
 - - - - - Constant C_d

0

5

10

15

20

25

30

 μ

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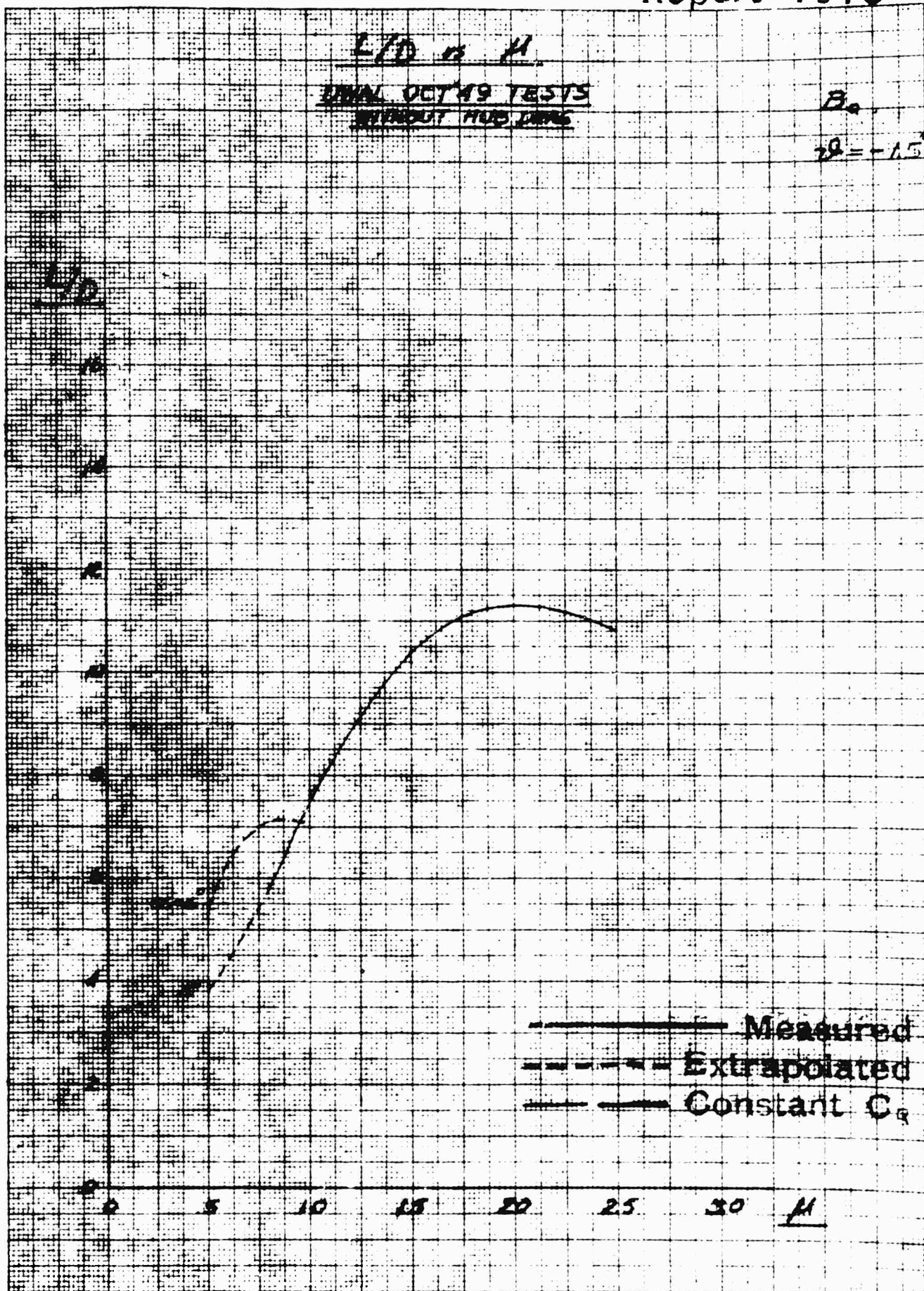
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$L/D \propto H$

FINAL OCT 49 TESTS
WITHOUT HUB DRAG

B_0

$\theta = -1.5^\circ$



KEUFFEL & ESSER CO.

No. 359 14 Millimeters, 5 mm lines accented, cm lines heavy

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CONFIDENTIAL

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L/D vs H
UNAL OCT 49 TESTS
WITHOUT HUB DRAG

β_0

$\beta_0 = -30^\circ$

L/D

16

14

12

10

8

6

4

2

0

0

5

10

15

20

25

30

H

Measured
Extrapolated
Constant C_2

PRX
12-15-49

KEUFFEL & ESSER CO.

No 359 14 millimeters, 5 mm lines accented, cm lines heavy

00-000000

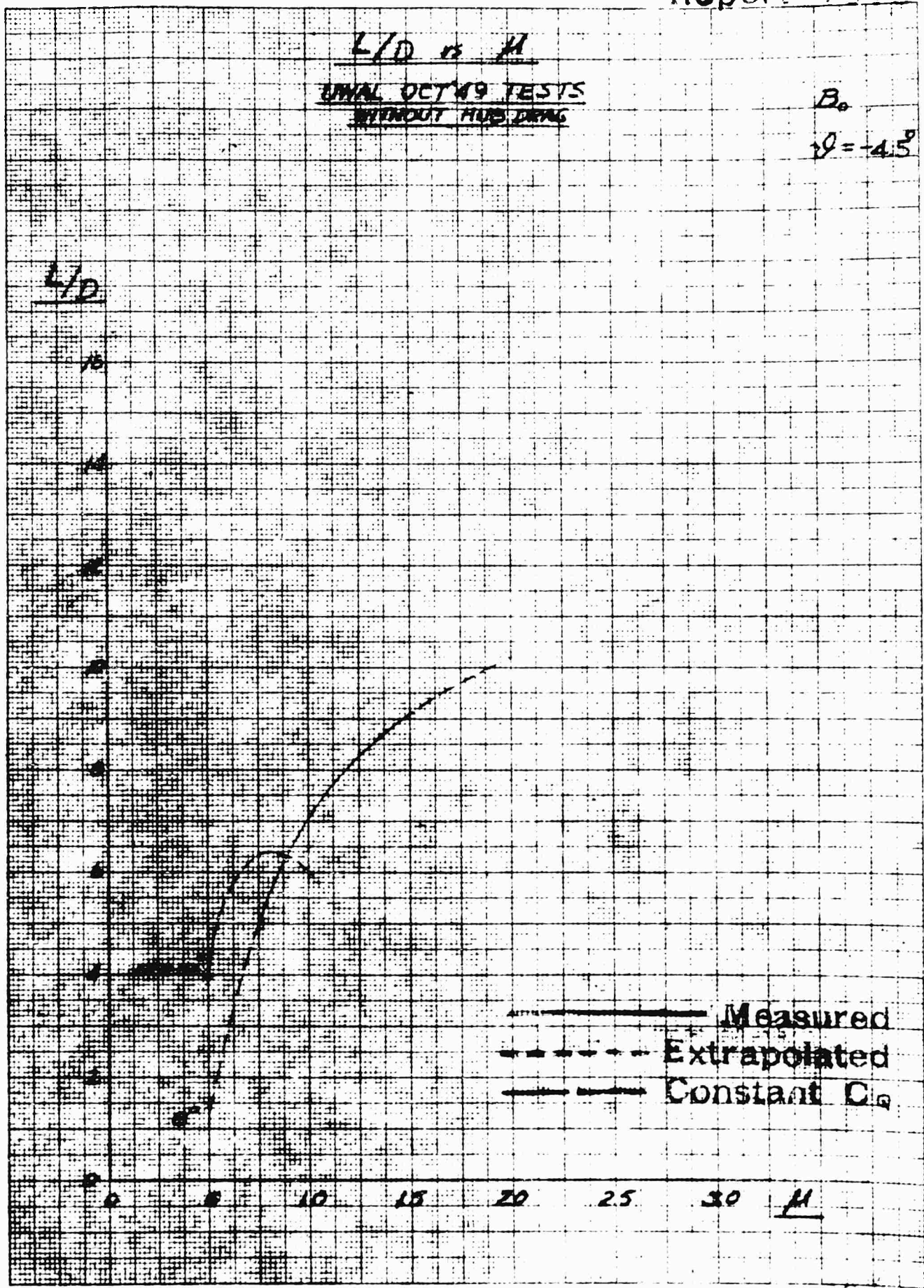
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L/D vs μ
UNAL OCT 49 TESTS
WITHOUT HUB DRAG

B_0
 $\beta = -4.5^\circ$

L/D



KEUFFEL & ESSER CO.

No. 35B-14. Millimeters, 5 mm lines accented, cm lines heavy
 MADE IN U.S.A.

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C_L VS β

UNVAL OCT 49 TESTS
WITHOUT HUB DEAG

B_0

$\Delta L = .5$

C_L

.07

.06

.05

.04

.03

.02

.01

0

-8

-4

-2

0

2

4

6

β

B_0

6°

4°

$C_R = 0$

— Measured
- - - Interpolated
- - - $C_R = 0$

$C_R = 10^\circ$

KEUFFEL & ESSER CO.

No. 353 14 Millimeter, 5 mm lines accented, cm lines heavy

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CL VS β

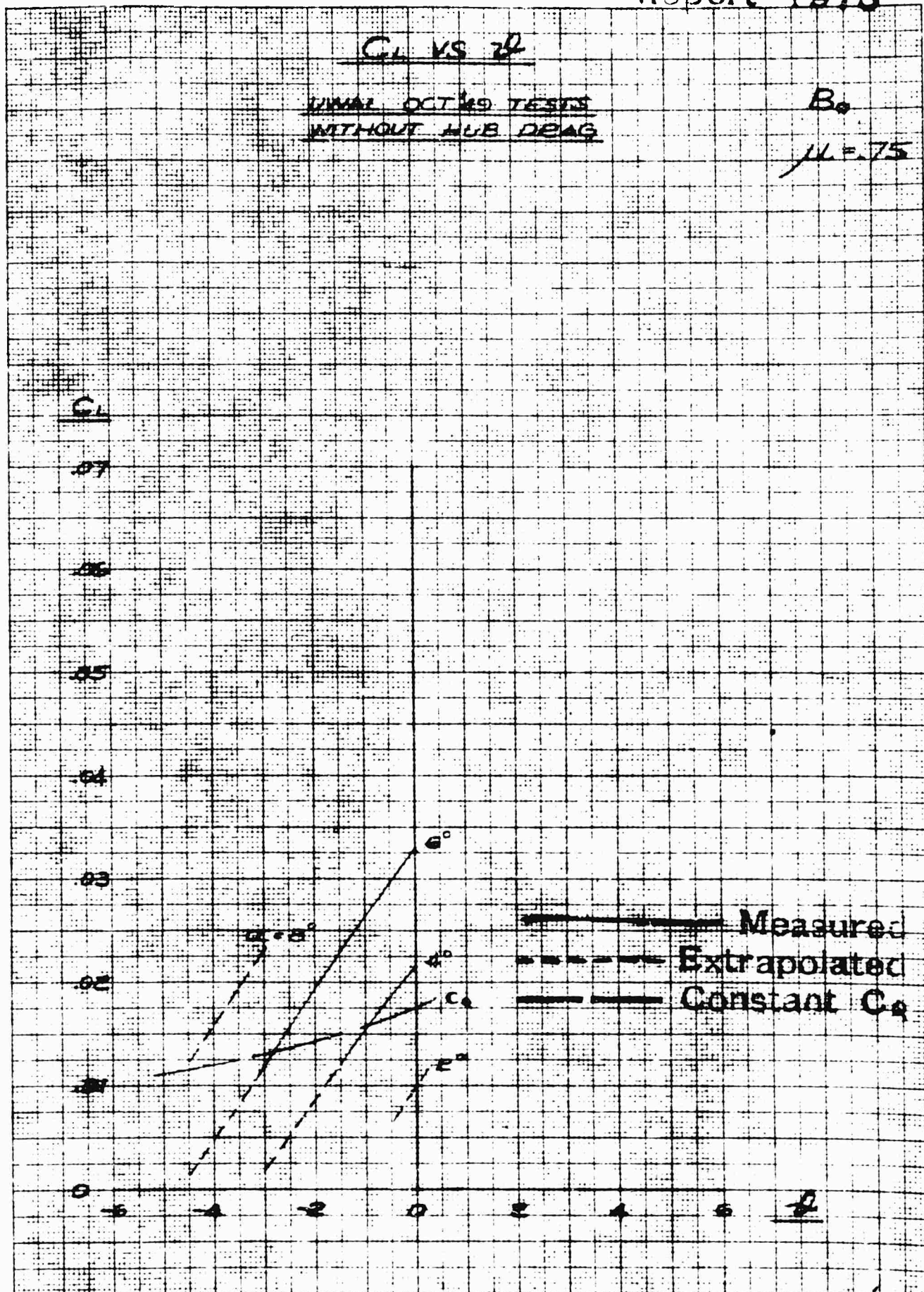
UNVAL OCT 49 TESTS
WITHOUT HUB DRAG

B.

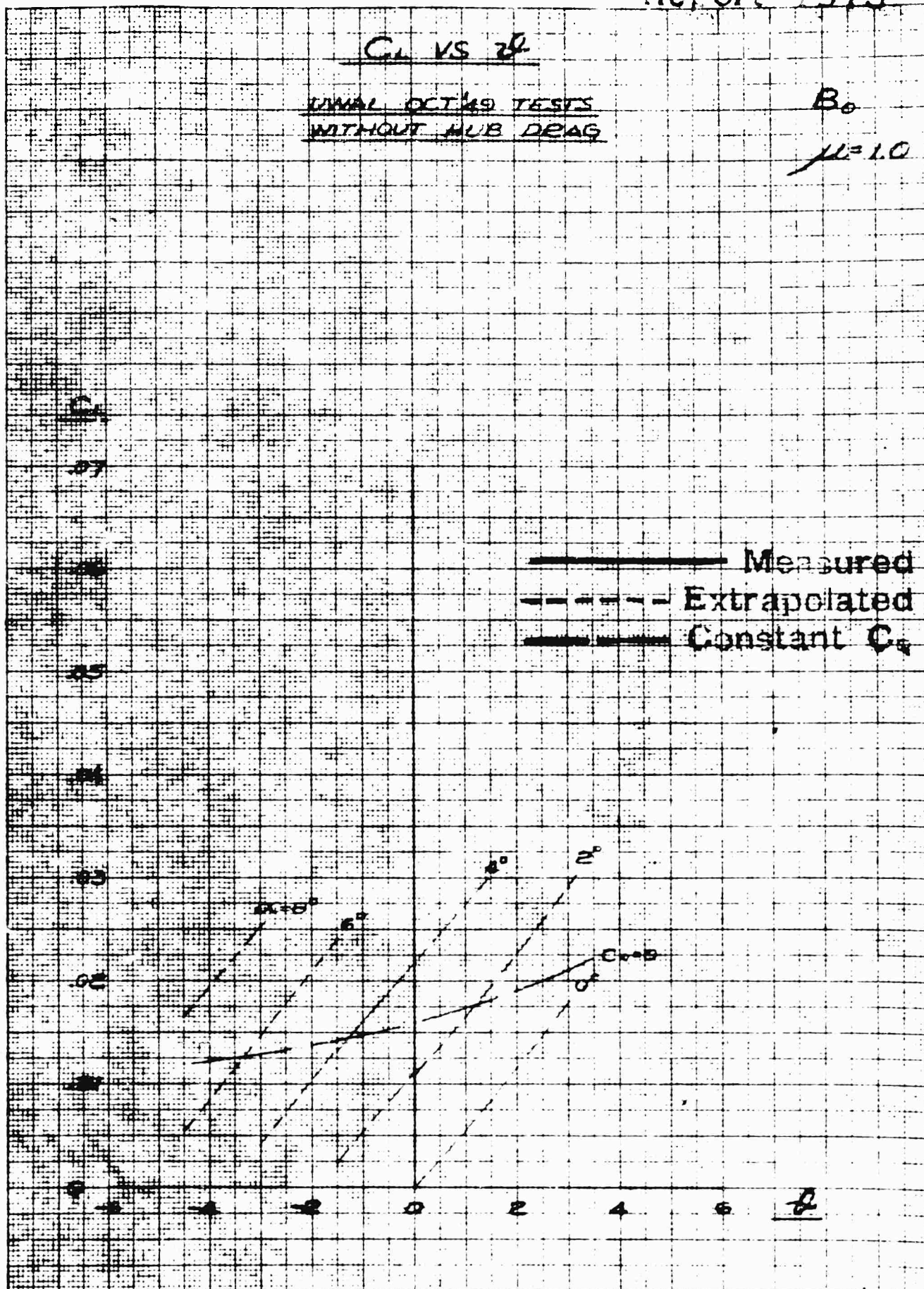
$\mu = .75$

KEUFFEL & ESSER CO.

No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy



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C_L VS α UNAL OCT 49 TESTS
WITHOUT HUB DRAG B_0 $\mu = 1.0$ 

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Report 1975

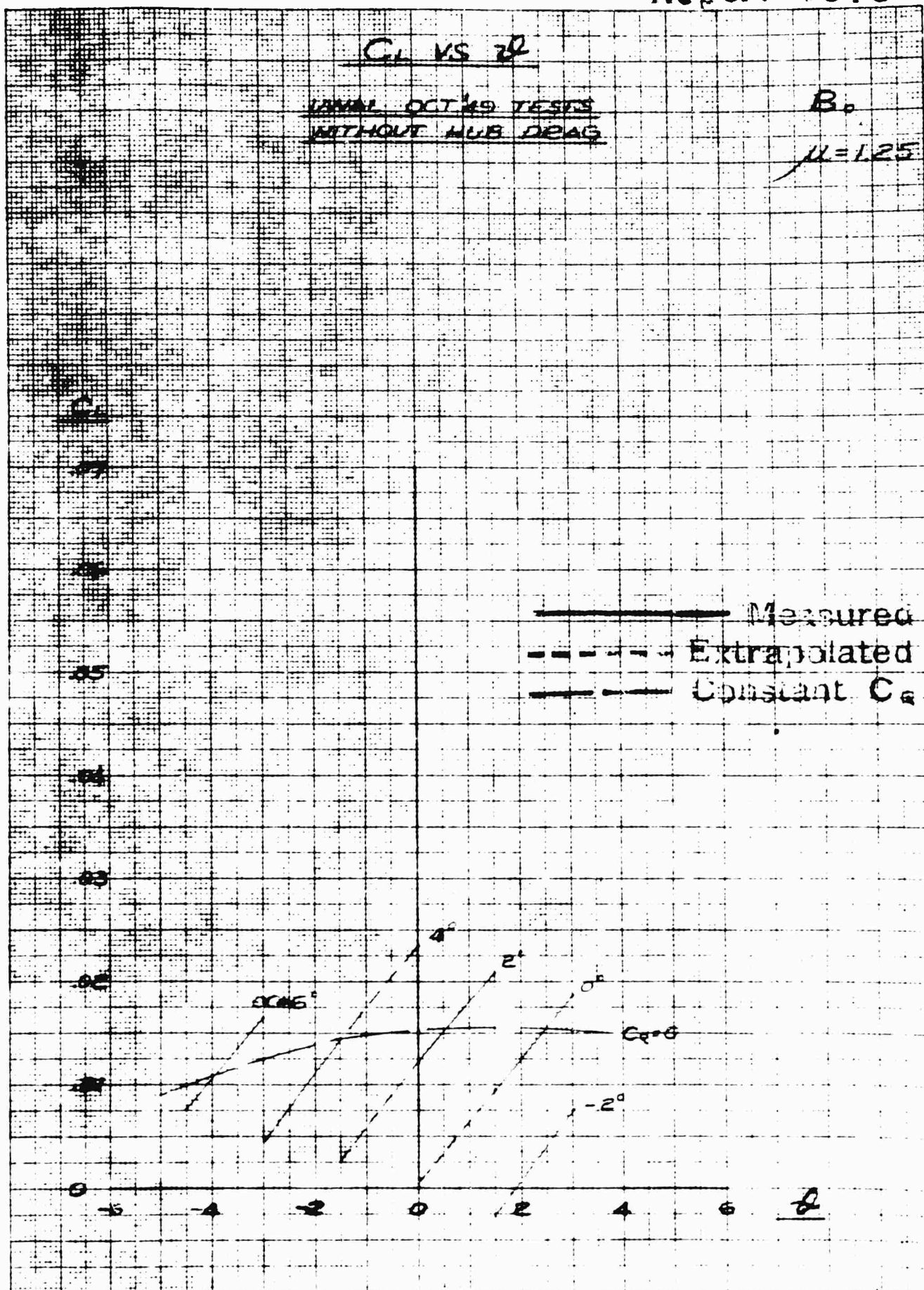
C_L VS α

LANAL OCT 49 TESTS
WITHOUT HUB DRAG

B_0

$\mu = 1.25$

————— Measured
----- Extrapolated
————— Constant C_a



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201

Re: [illegible]

C_L VS α

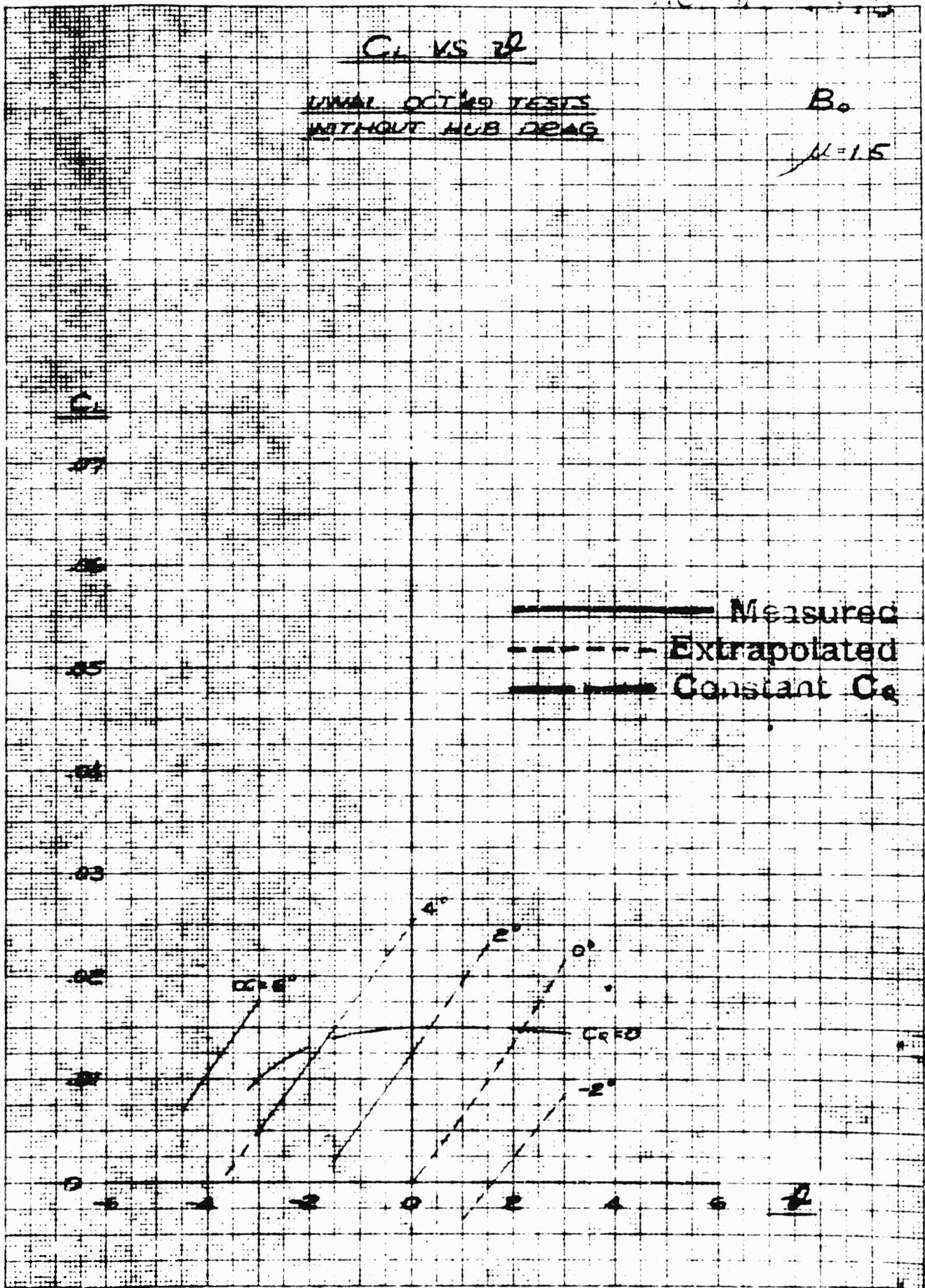
WIND TUNNEL TESTS
WITHOUT HUB DRAG

B_0

$N=1.5$

KEUFFEL & ESSER CO.

No. 359 14 Millimeters, 5 mm lines accented, cm lines heavy



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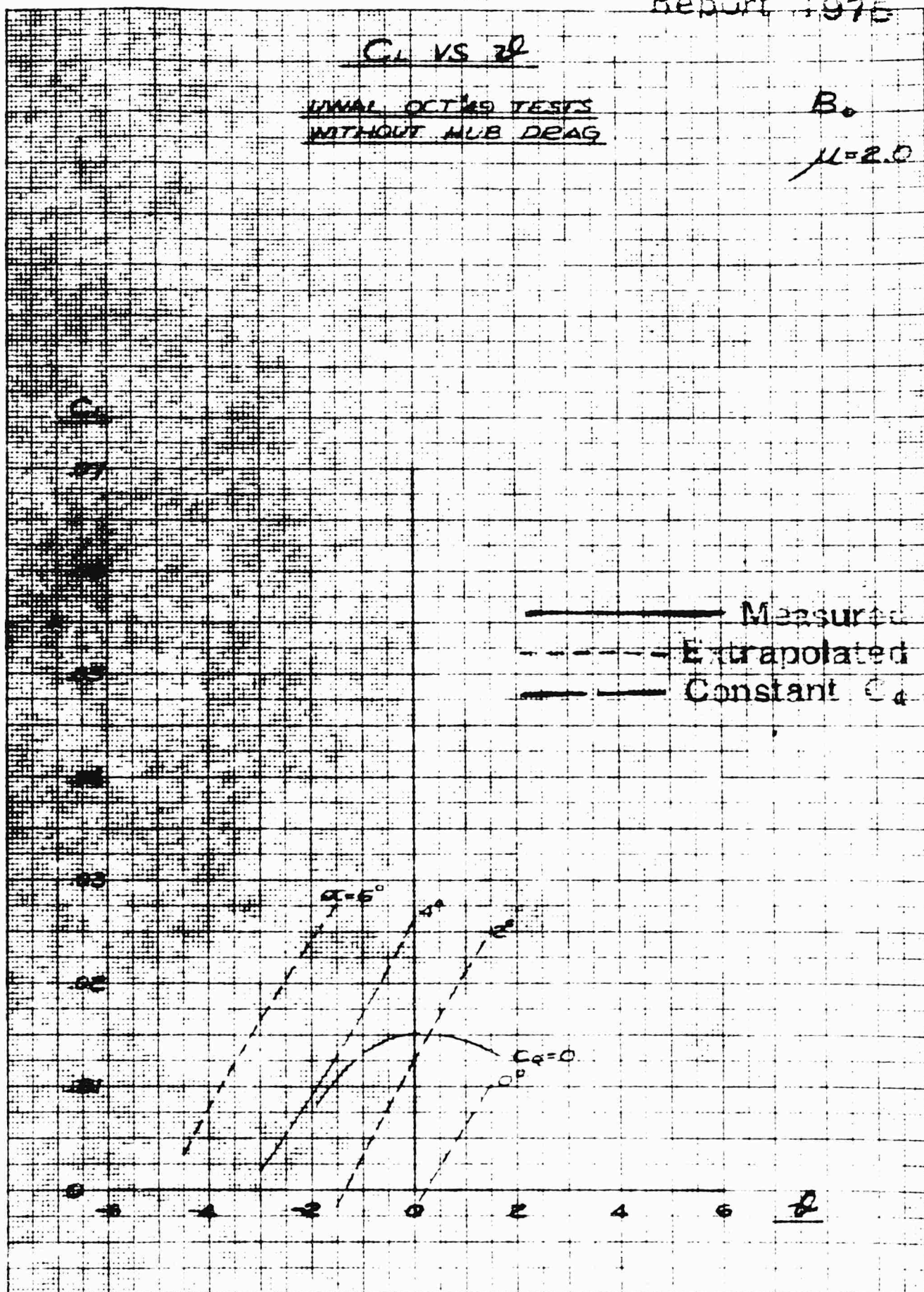
C_L VS α

UNVAL OCT 49 TESTS
WITHOUT ALB DRAG

B_0

$\mu = 2.0$

————— Measured
----- Extrapolated
————— Constant C_d



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C_L VS α

WIND TUNNEL TESTS
WITHOUT HUB DRAG

B_0

$\mu = 2.5$

C_L

.07

.06

.05

.04

.03

.02

.01

0

————— Measured
----- Extrapolated
————— Constant C_d

$\alpha = 2^\circ$

0°

$C_d = 0$

0 2 4 6 α

KEUFFEL & ESSER CO.

No. 3-7-14 Millimeters, 5 mm lines accented, cm lines heavy

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Report 1975

C_T VS α

10³ C_T

UNVAL OCT '49 TESTS
WITHOUT HUB DRAG

B₀

11.5

40

36

32

28

24

20

16

12

8

4

0

-6

-4

0

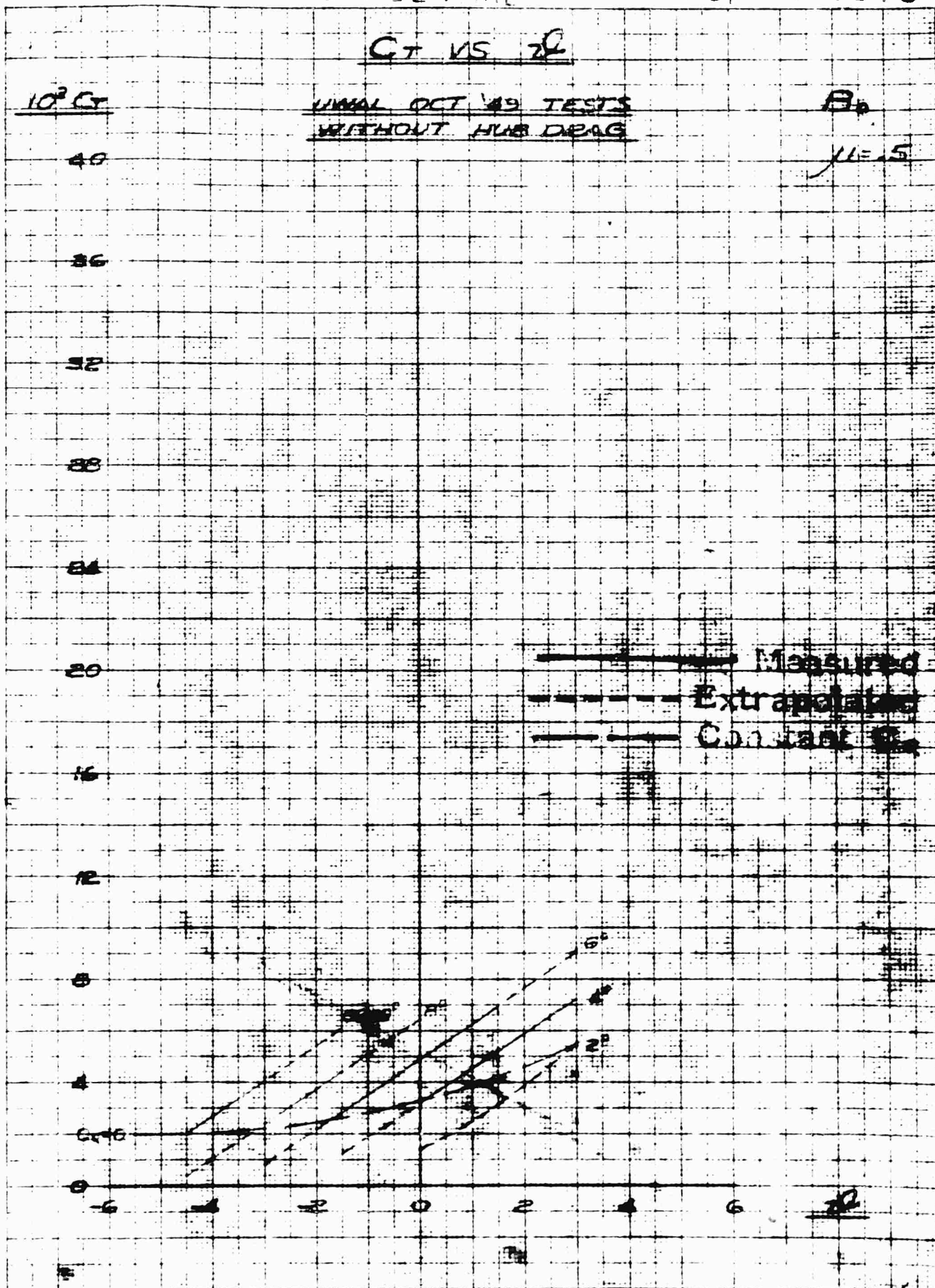
2

4

6

8

Measured
Extrapolated
Constant B₀



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Report 1975

CT VS α

$10^3 CT$

UNION OCT '49 TESTS
WITHOUT HUB DRAG

B.

$\mu = .75$

40

35

32

28

24

20

16

12

8

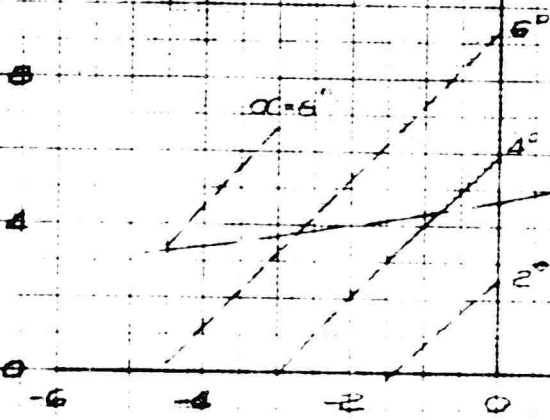
4

0

Measured
Extrapolated
Continued C_q

-6 -4 -2 0 2 4 6

α



CT VS α $10^3 C_T$ UNVAL OCT '49 TESTS
WITHOUT HUB DRAG B_0 $\mu = 1.0$

40

36

32

28

24

20

16

12

8

4

0

————— Measured
 - - - - - Extrapolated
 ———— Overall C_q

-4

-2

0

2

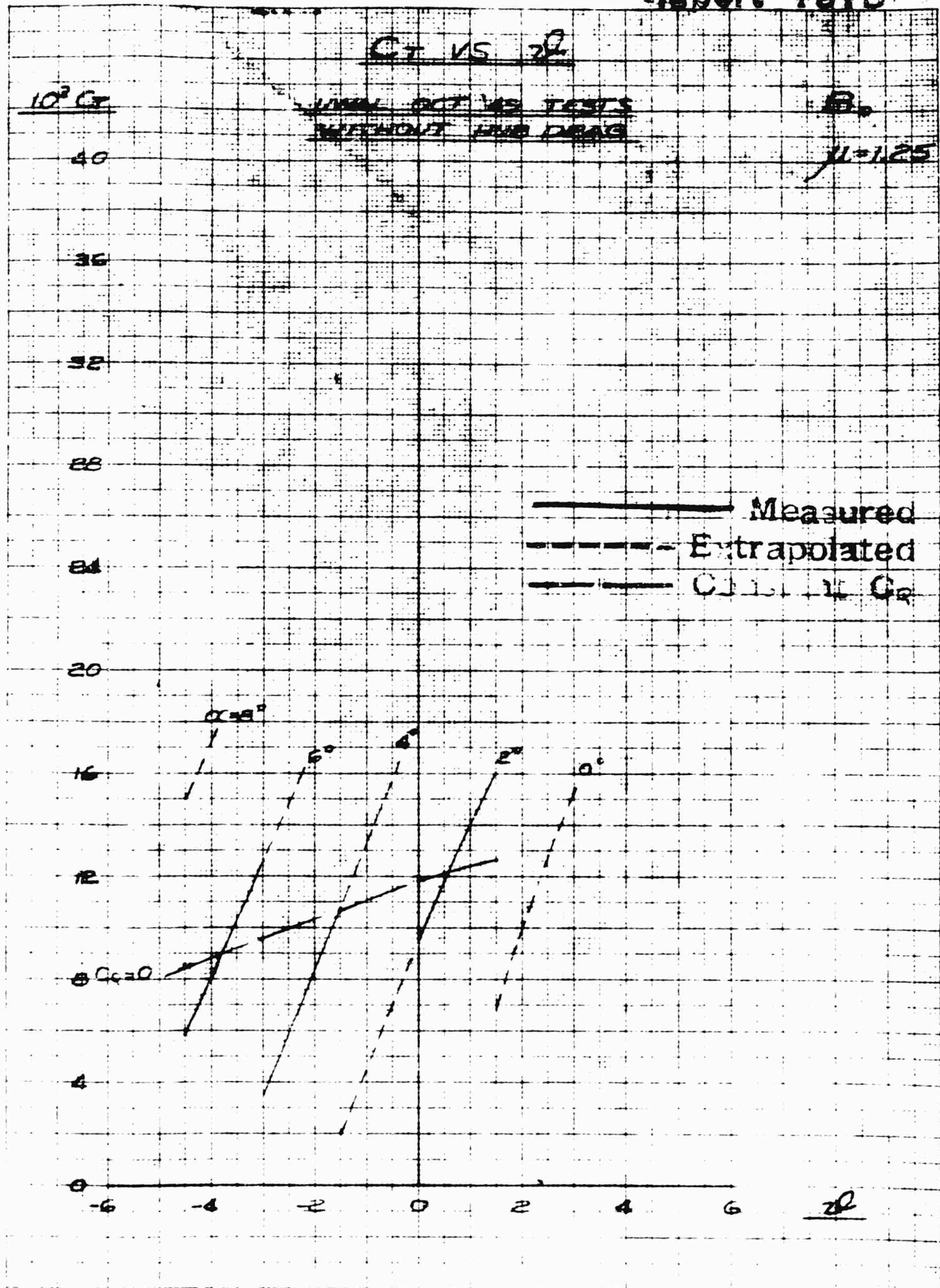
4

6

 α $\alpha = 15^\circ$ 6° 4° 2°

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Report 1973

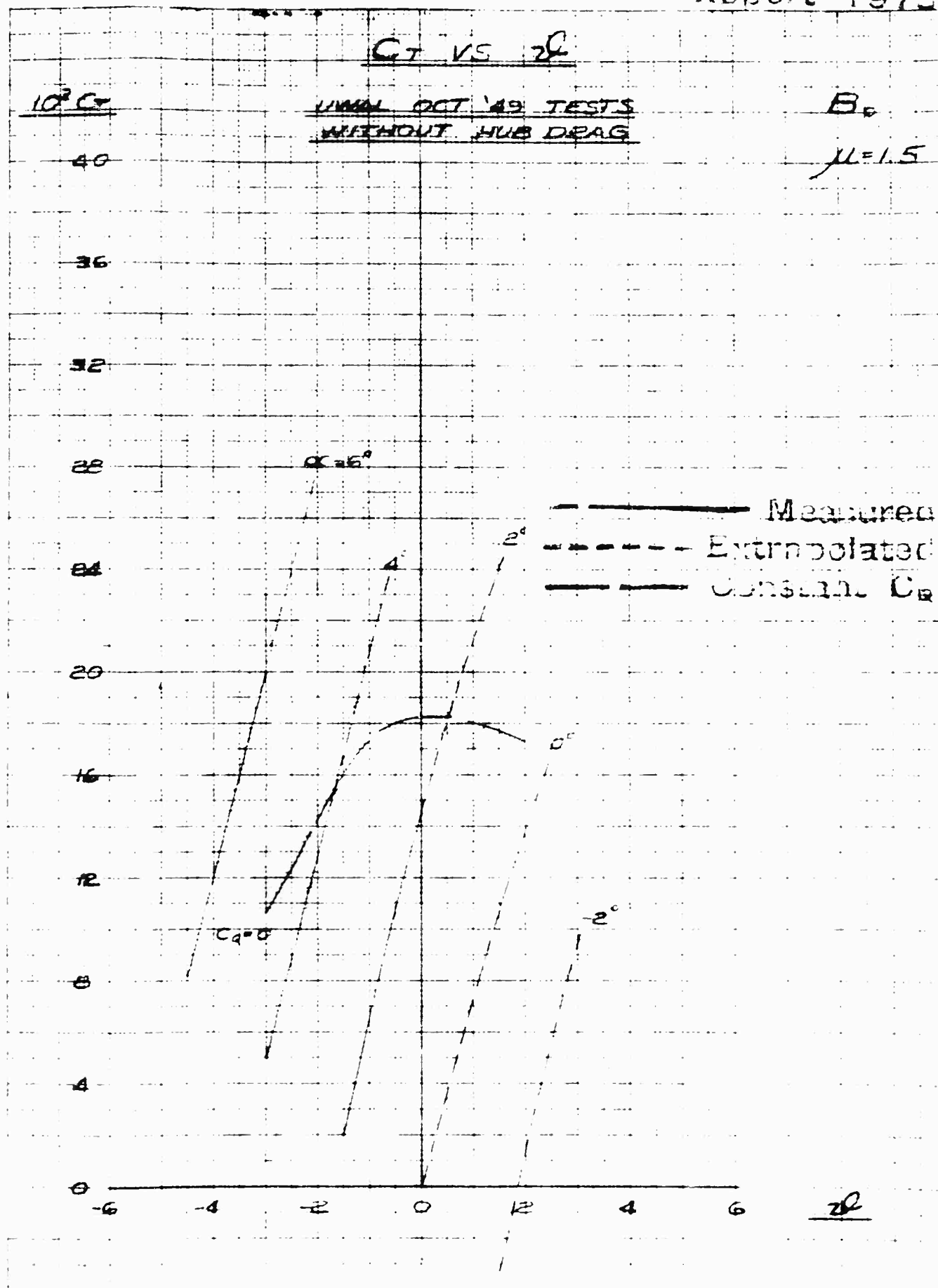
C_T VS α

$10^3 C_T$

UNVAL OCT '49 TESTS
WITHOUT HUB DRAG

B_c

$\mu = 1.5$



RIGHT LINE CO

No. 10-11 Millimeter Scale

CT VS α

$10^3 C_T$

UNAL OCT '49 TESTS
WITHOUT HUB DRAG

B_c

$\mu = 2.0$

40

36

32

28

24

20

16

12

8

4

0

-6

-4

-2

0

2

4

6

α

$\alpha = 6^\circ$

4°

2°

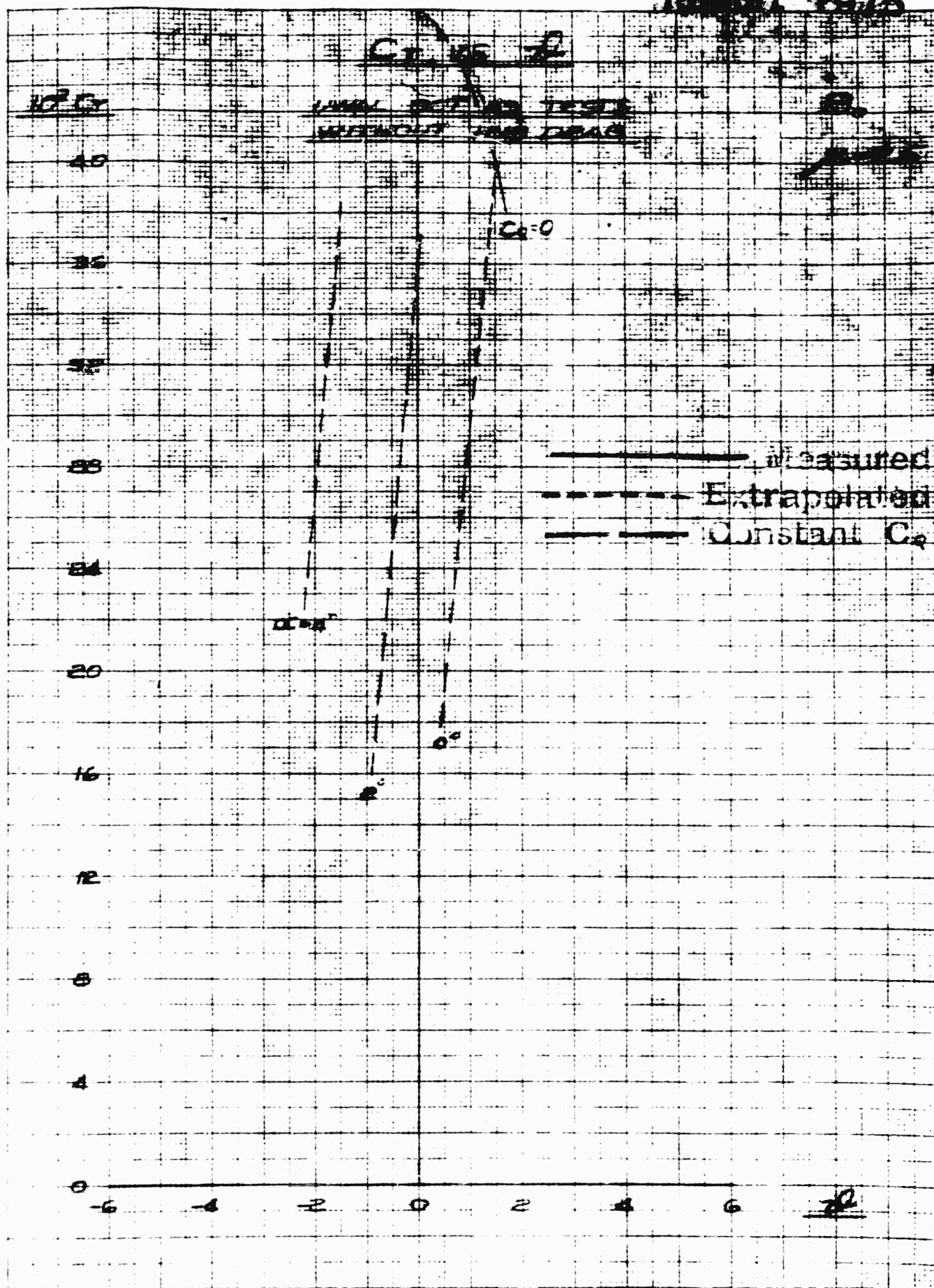
$C_d = 0$

0°

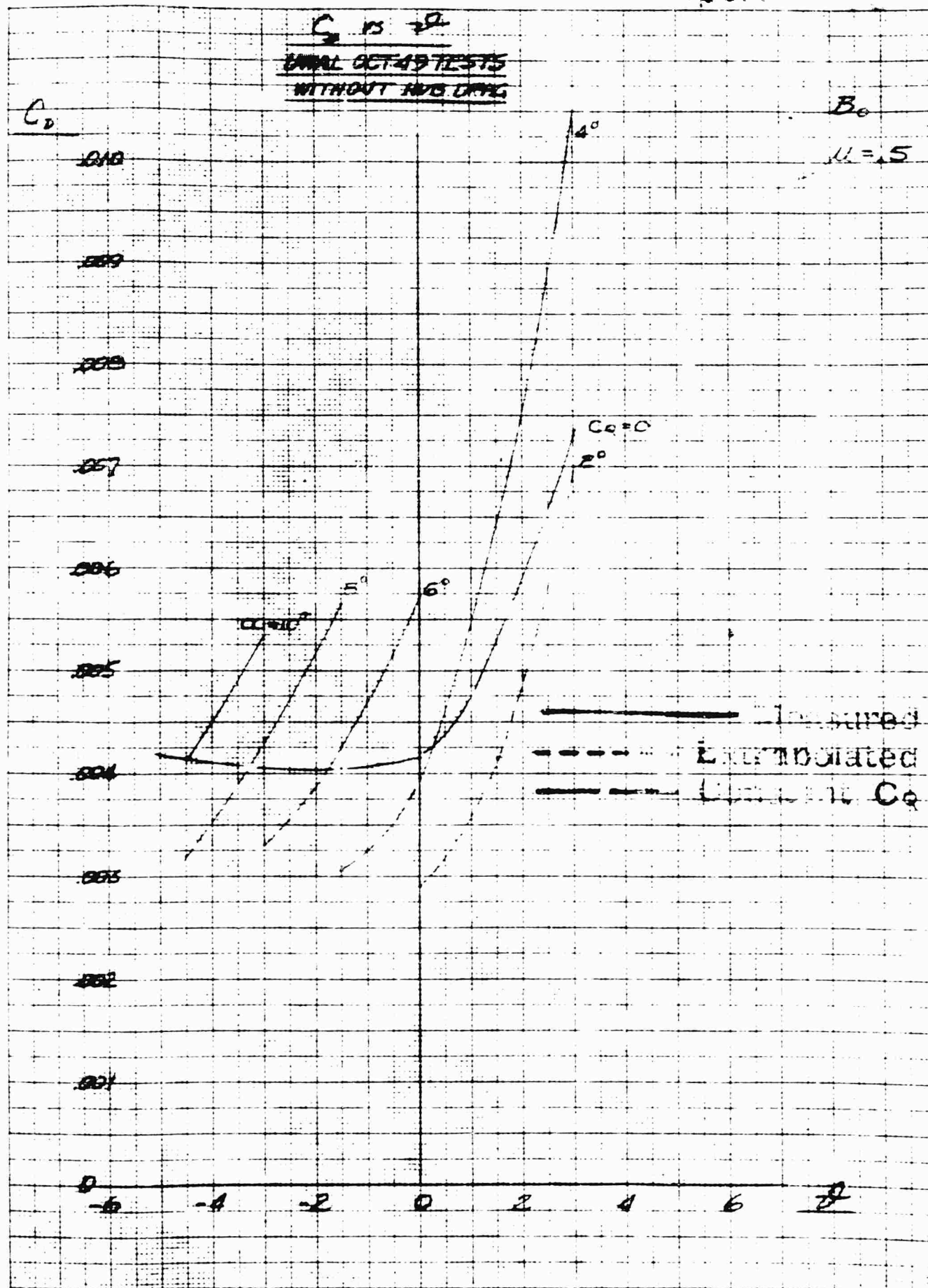
— Measured
--- Extrapolated
— Constant C_d

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C_D is 2^2
UNAL OCT 49 TESTS
WITHOUT HUB DRAG



Report 1975

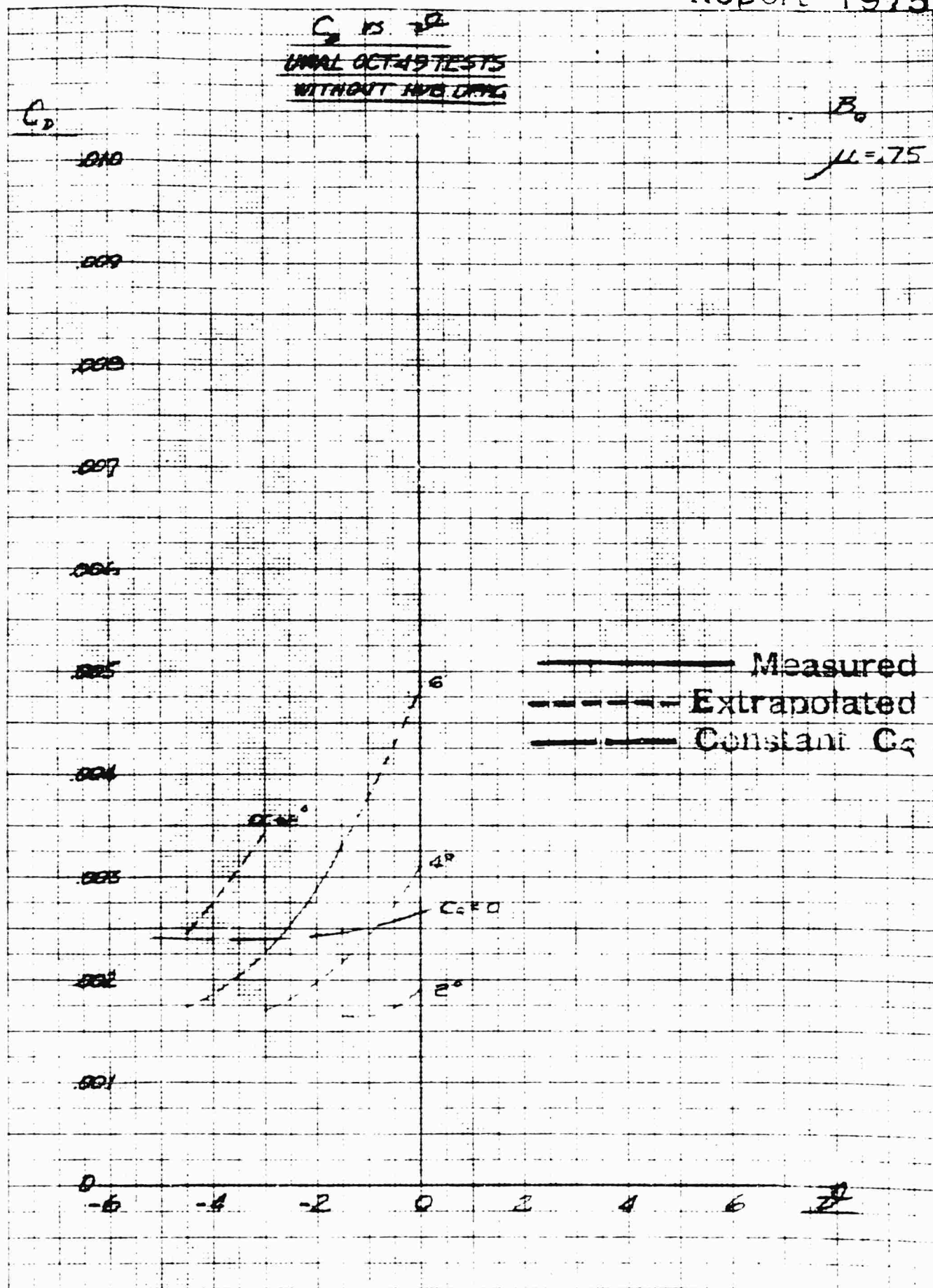
212

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9 13 20
UNRAI OCT 49 TESTS
WITHOUT HIV DRUG

6

3

$$\mu = 1.75$$


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C_0 is β^2
WALL OCT 49 TESTS
WITHOUT HPG DING

C_0

B_0

$\mu = 1.0$

.010

.009

.008

.007

.006

.005

.004

.003

.002

.001

$C_0 = 0$

$\alpha = 6^\circ$

4°

Measured

Extrapolated

Constant C_0

-6 -4 -2 0 2 4 6 β

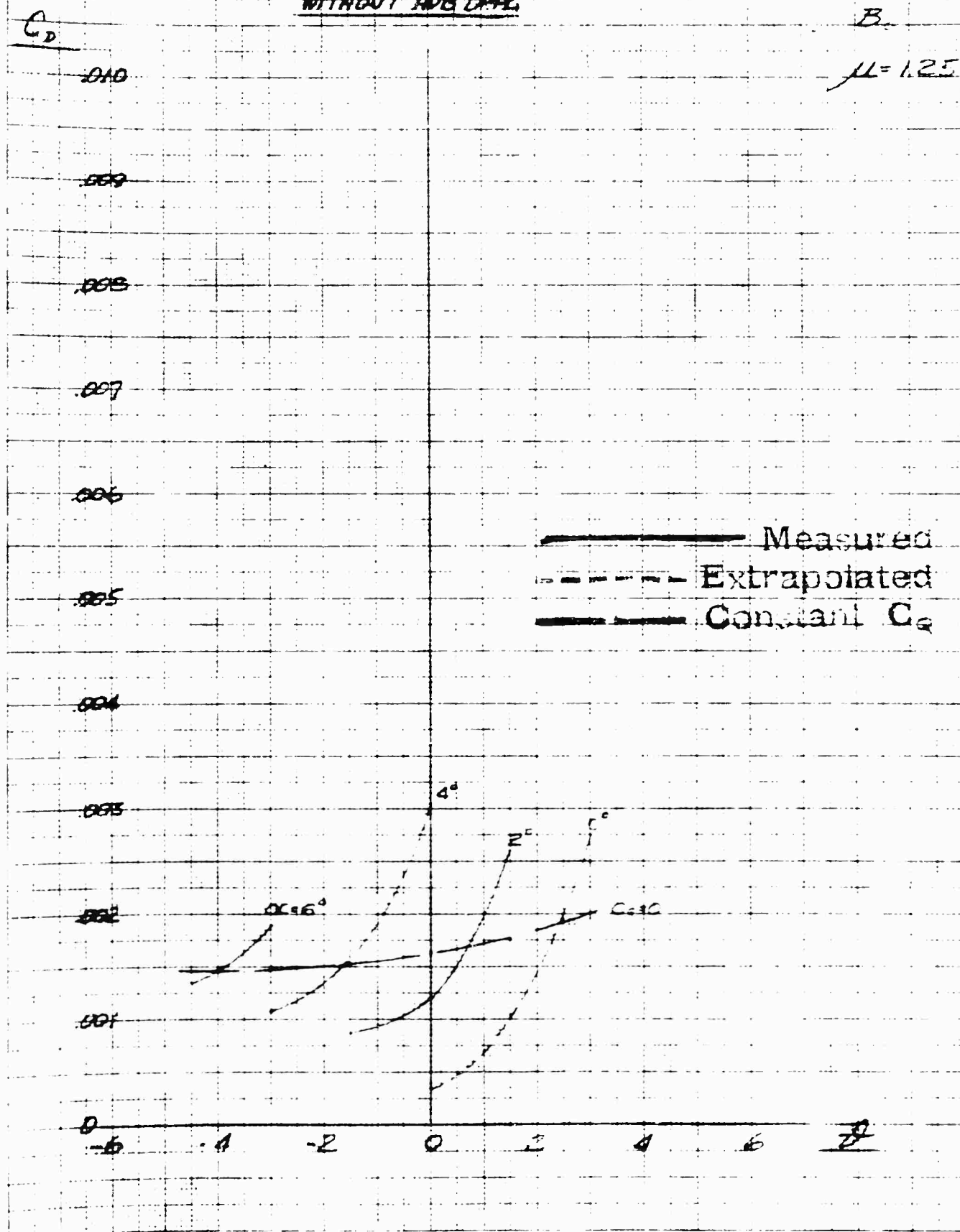
KEUFFEL & ESSER CO.

No. 359-14 Millimeter, 5 mm. lines, oriented, on lines heavy

SB 11
11-12-49

C_p IS z^2
UNRAI OCT 49 TESTS
WITHOUT HUB DRAG

B

 $\mu = 1.25$ 

215

REDON

C_p vs β
UNAL OCT49 TESTS
WITHOUT HUB LAMP

 C_p B_c $\mu=1.5$

.010

.009

.008

.007

.006

.005

.004

.003

.002

.001

0

-6

-4

-2

0

2

4

6

 β

———— Measured
 - - - - - Extrapolated
 ———— Constant C_q

 $\alpha=16^\circ$

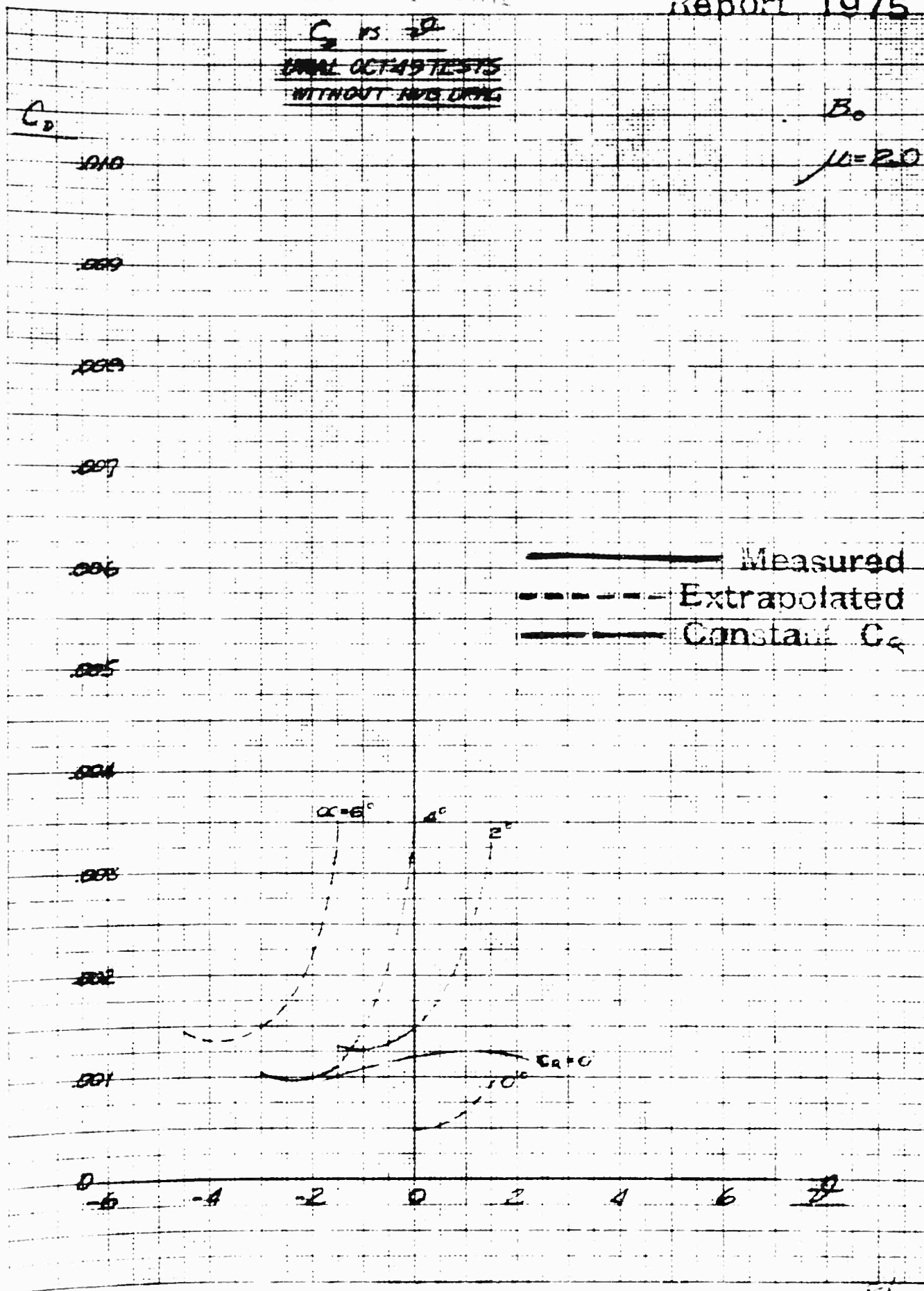
E

C_q

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C_p vs. β
OCT 49 TESTS
WITHOUT HPS DRUG



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C_p vs β
UNAL OCT-49 TESTS
WITHOUT HUB DRAG

C_p

B_c

$\mu = 2.5$

.010

.009

.008

.007

.006

.005

.004

.003

.002

.001

0

————— Measured
 - - - - - Extrapolated
 ———— $C_G = 0$

$\beta = 2^\circ$

β°

$C_G = 0$

-4

-2

0

2

4

6

β

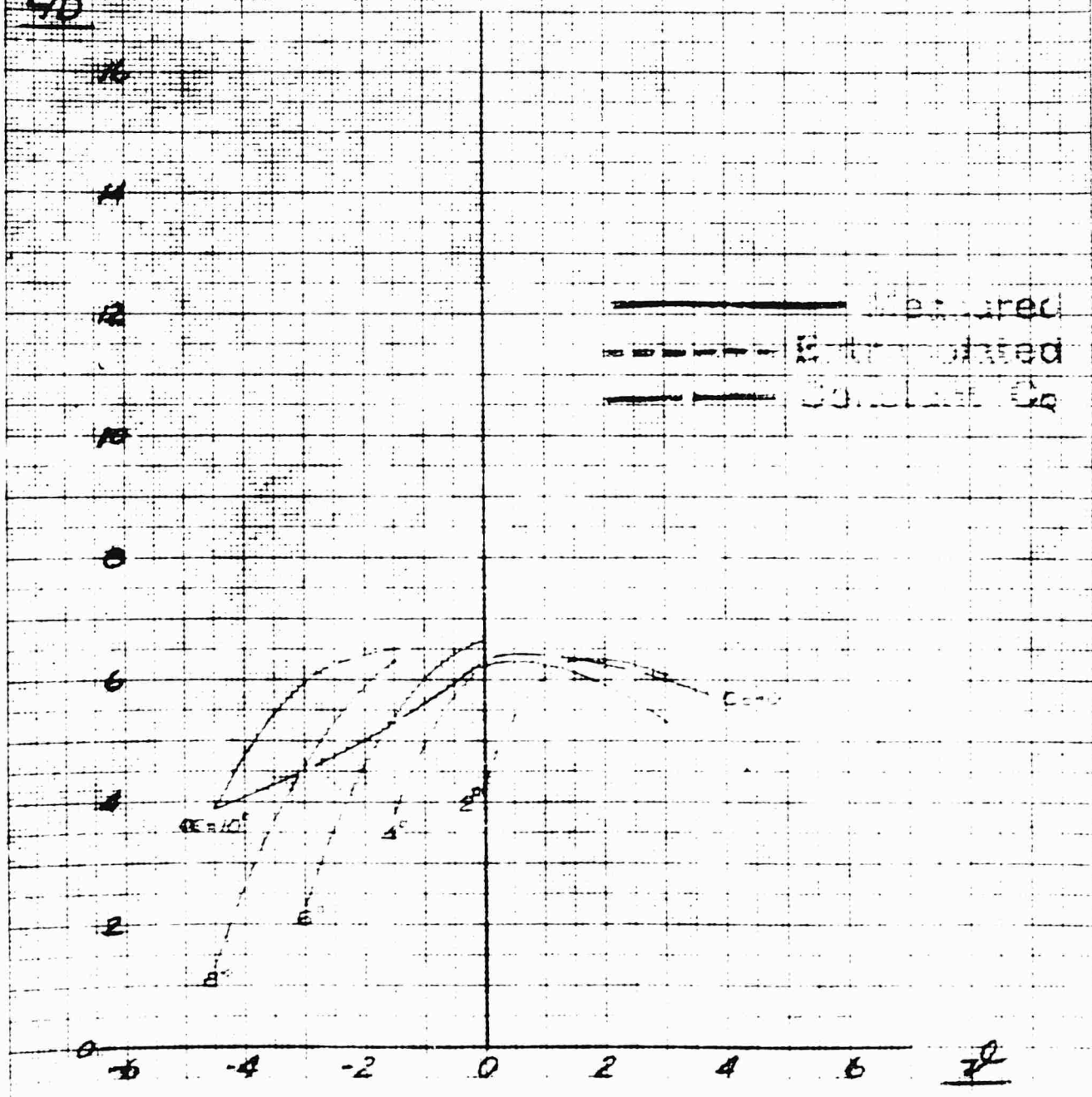
L/D vs β
LAPVAL OCT 49 TESTS
WITHOUT HUB DRAG

B_0

$\mu = .5$

L/D

————— Measured
 - - - - - Extrapolated
 ———— Correlation Co



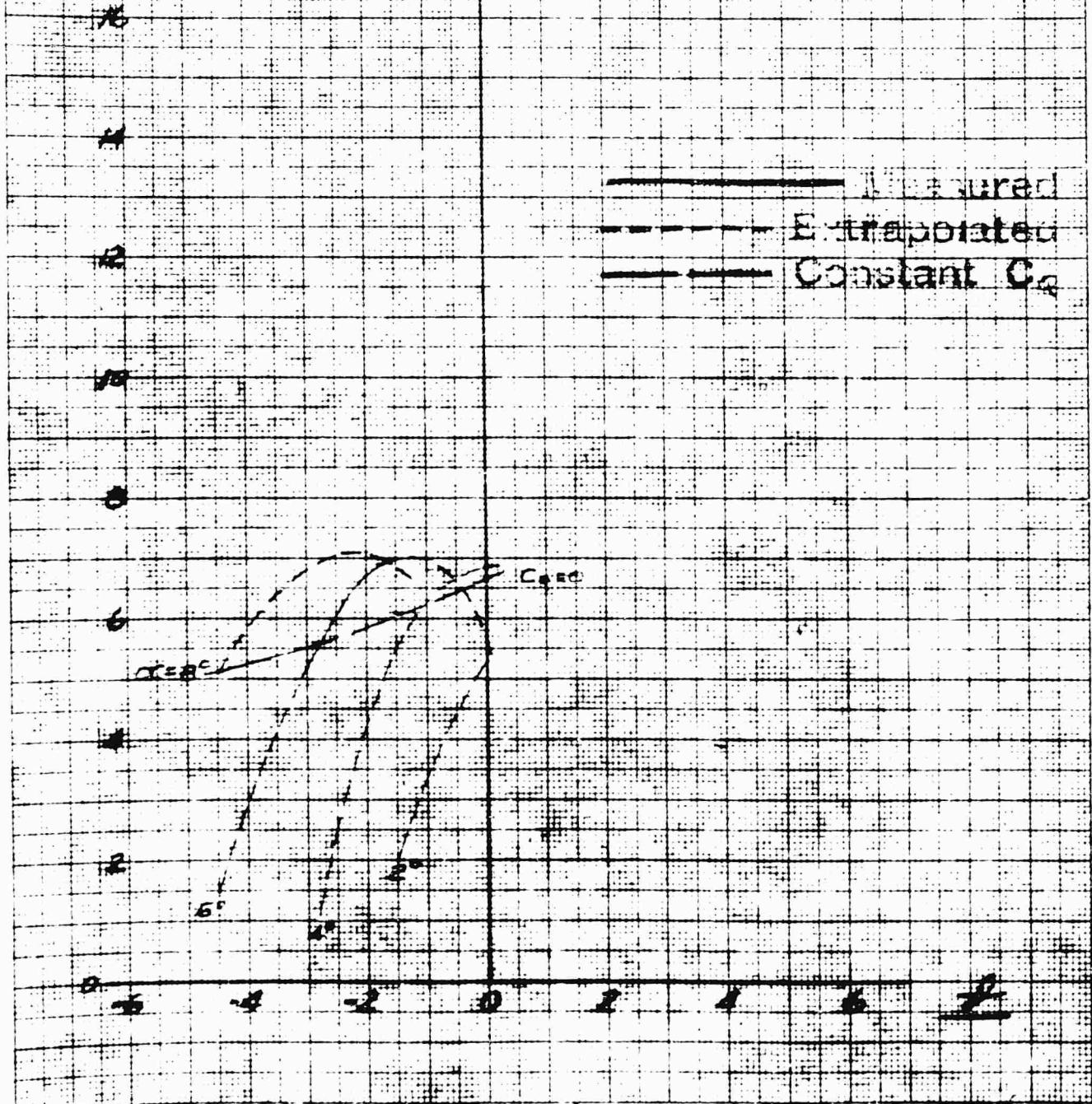
L/D vs α
UNRAIL OCT 49 TESTS
WITHOUT HUB DRAG

B.

$\mu = 75$

L/D

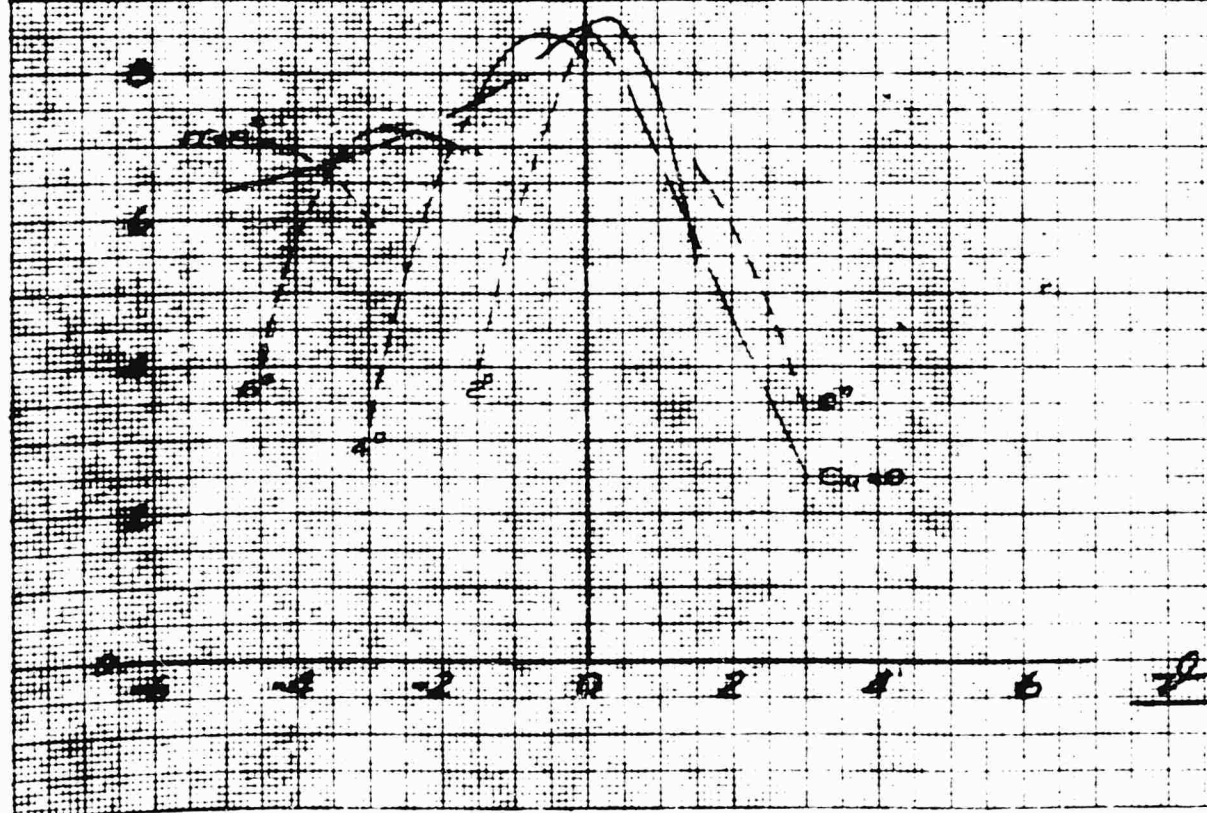
————— Measured
----- Extrapolated
————— Constant C_d



L/D vs β
UNIV. OCT 49 TESTS
WITHOUT HUB DRAG

 B_0 $U=1.0$ L/D

———— Measured
 - - - - - Extrapolated
 ———— Constant C_d



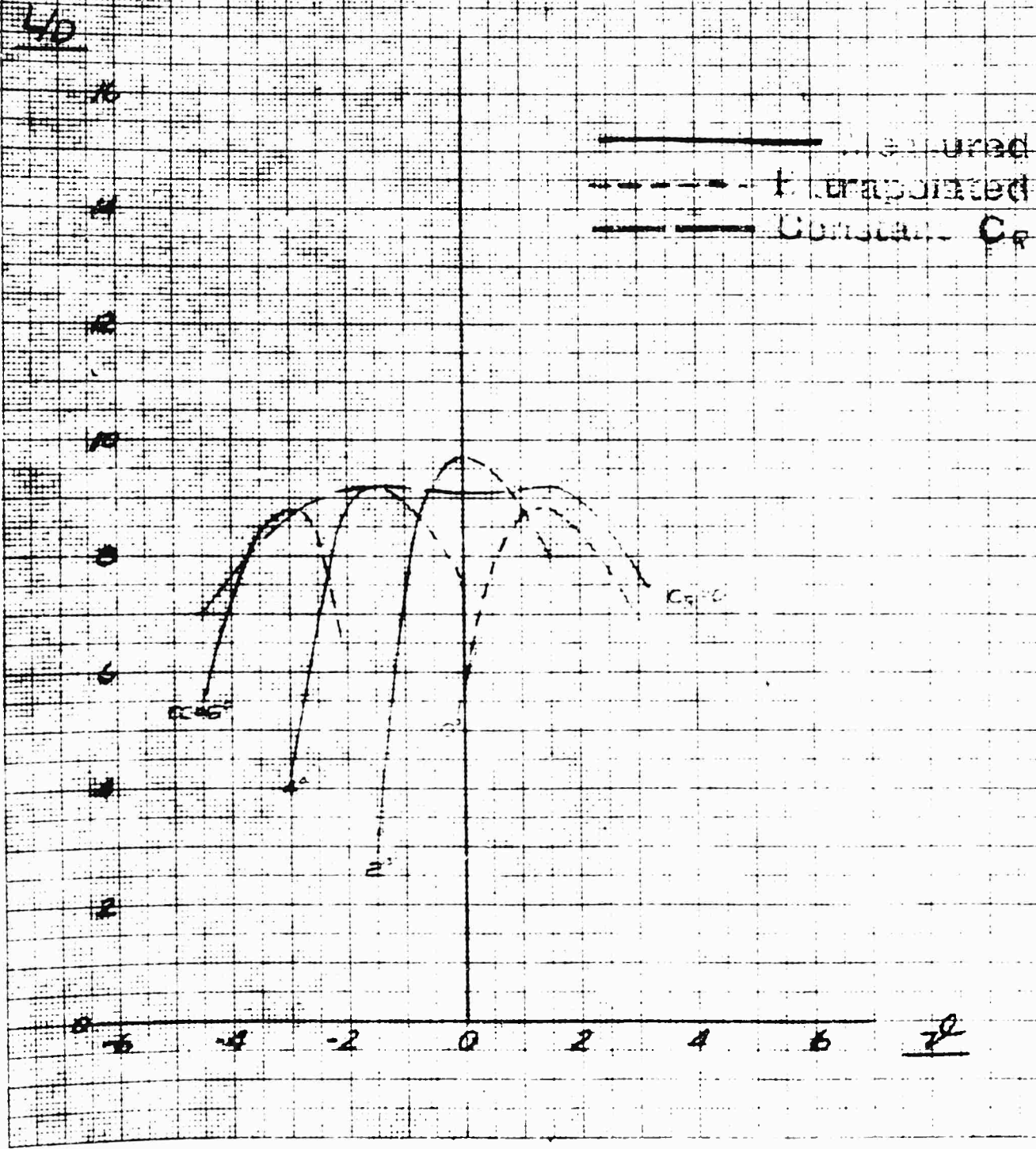
JUN 1975

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L/D vs β
UNAL OCT 49 TESTS
WITHOUT HUB DRAG

B_0

$\mu = 1.25$



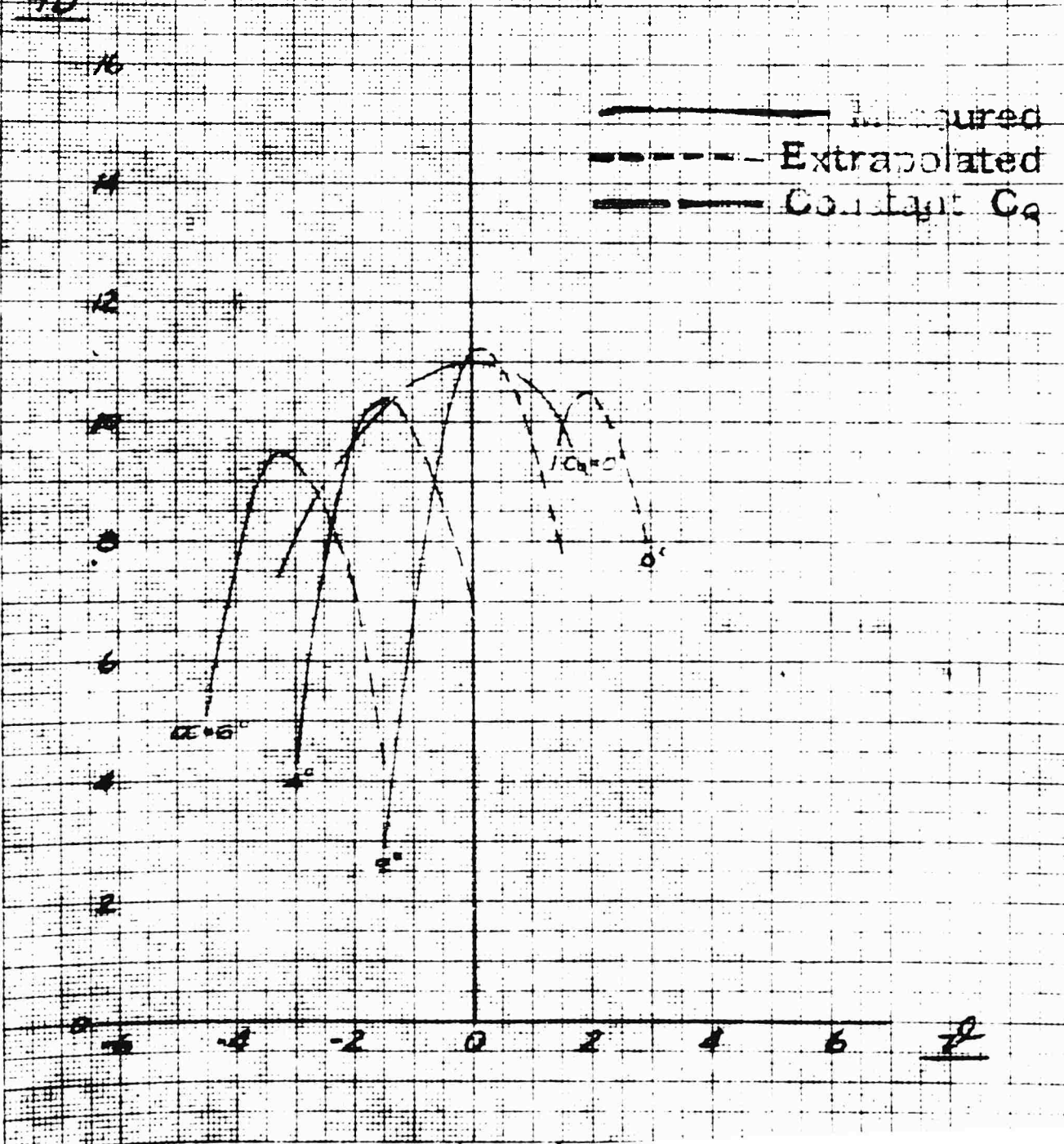
L/D vs β
UNIV. OCT 49 TESTS
WITHOUT HUB DRAG

B_0

$\mu = 1.5$

L/D

Measured
Extrapolated
Constant C_q



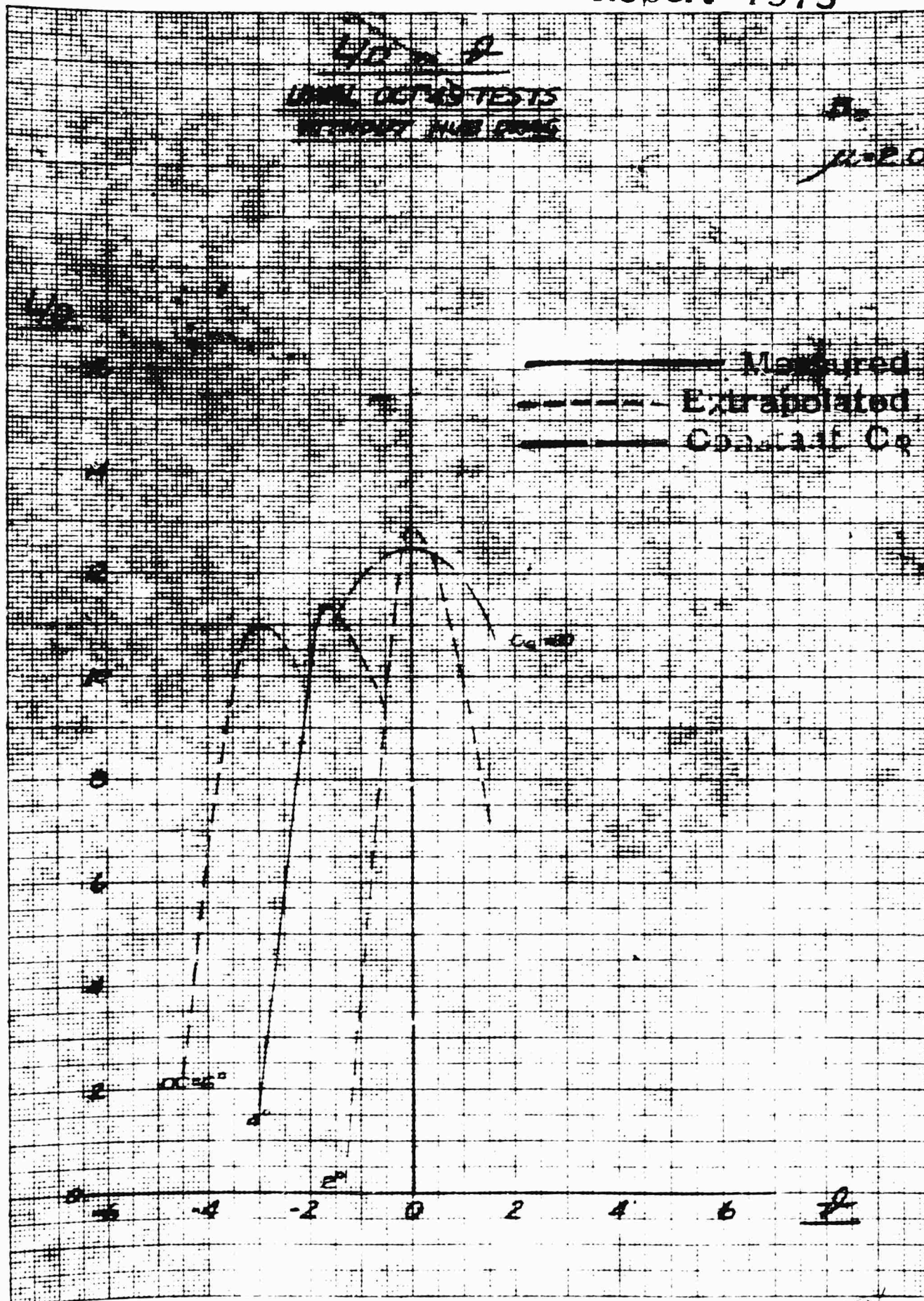
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Level Oct 1975 TESTS
WITHOUT THE PING

11-20

Measured
Extrapolated
Coastal Co



011

224

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L/D vs β

LOWAL OCT 49 TESTS
WITHOUT HUB DRAG

B_0

$\mu = 2.5$

L/D

— Measured
- - - - - Extrapolated
— Constant C_d

$C_d = 0$

$\mu = 2.5$

-6 -4 -2 0 2 4 6 β

NEUFEL & ESSER CO.

No. 205 14 millimeters, 5 mm lines accented, cm lines heavy

011

107

134 225
 R 300 1975

C_d VS z

UWAL OCT '49 TESTS
WITHOUT HUB DRAG

B_0

$\mu = 5$

$10^3 C_d$

.4

.2

0

-.2

-.4

-.6

-.8

-.10
 -6

-4

-2

0

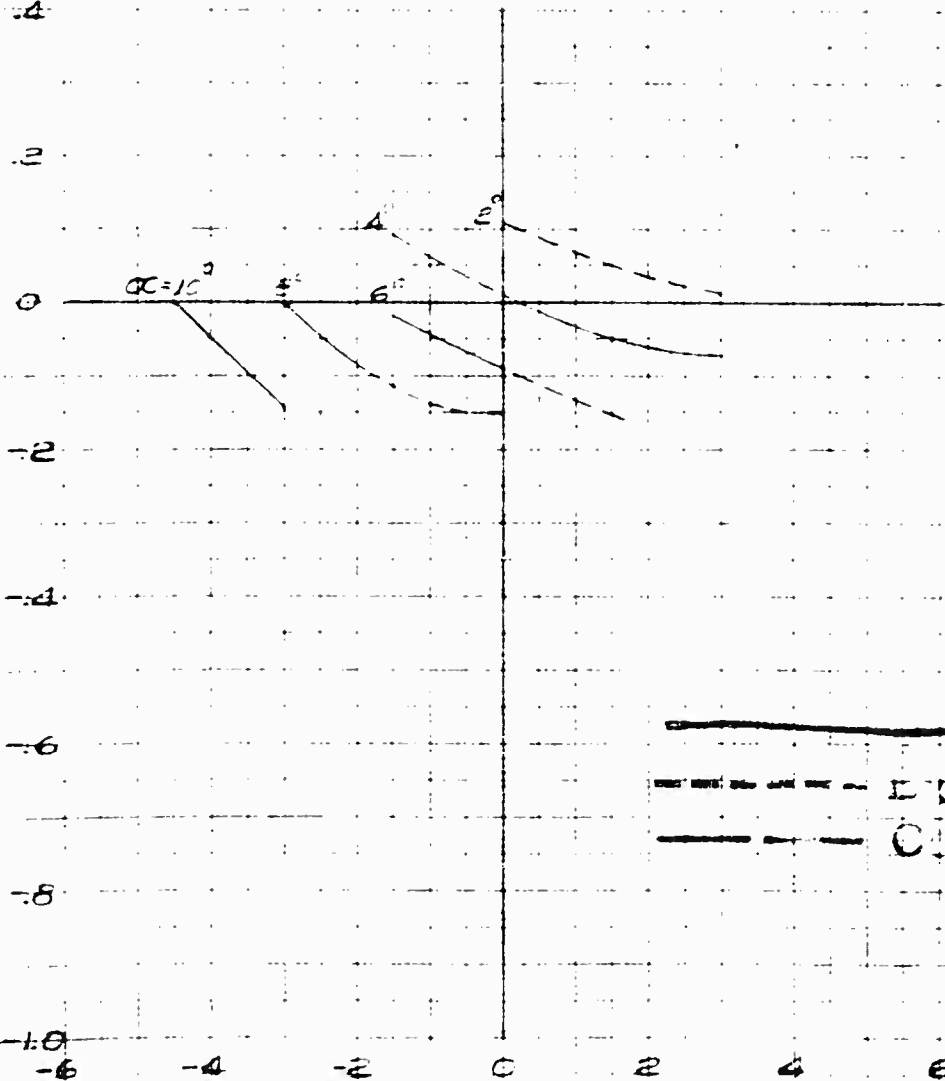
2

4

6

z

————— Measured
 - - - - - Extrapolated
 - - - - - Constant C_d



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C_D VS z_0

UWAL OCT 49 TESTS
WITHOUT HUB DRAG

B_0

11.75

$10^3 C_D$

4

2

0

-2

-4

-6

-8

-10

-6

-4

-2

0

2

4

6

20

2°

4°

6°

$\alpha = 6$

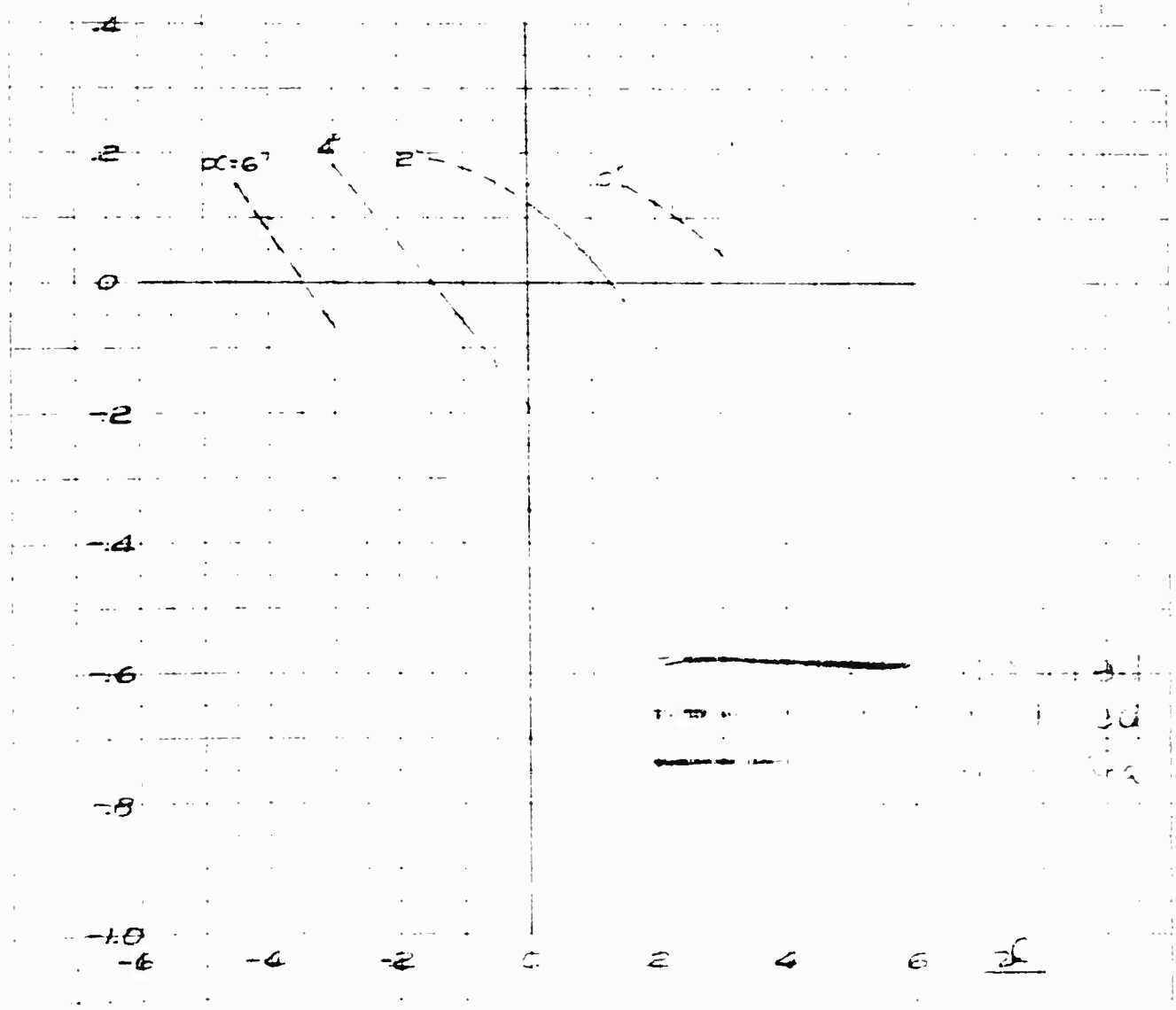
Measured
Extrapolated
Constant C_D

C_g VS γ

UWAL OCT '49 TESTS
WITHOUT HUB DRAG

B₀
 11.10

10³ C_g



C_0 VS z_0

UWAL OCT 49 TESTS
WITHOUT HUB DEAD

E_0

$U = 1.15$

$10^3 C_0$

.4

.2

0

-.2

-.4

-.6

-.8

-1.0

-6

-4

-2

0

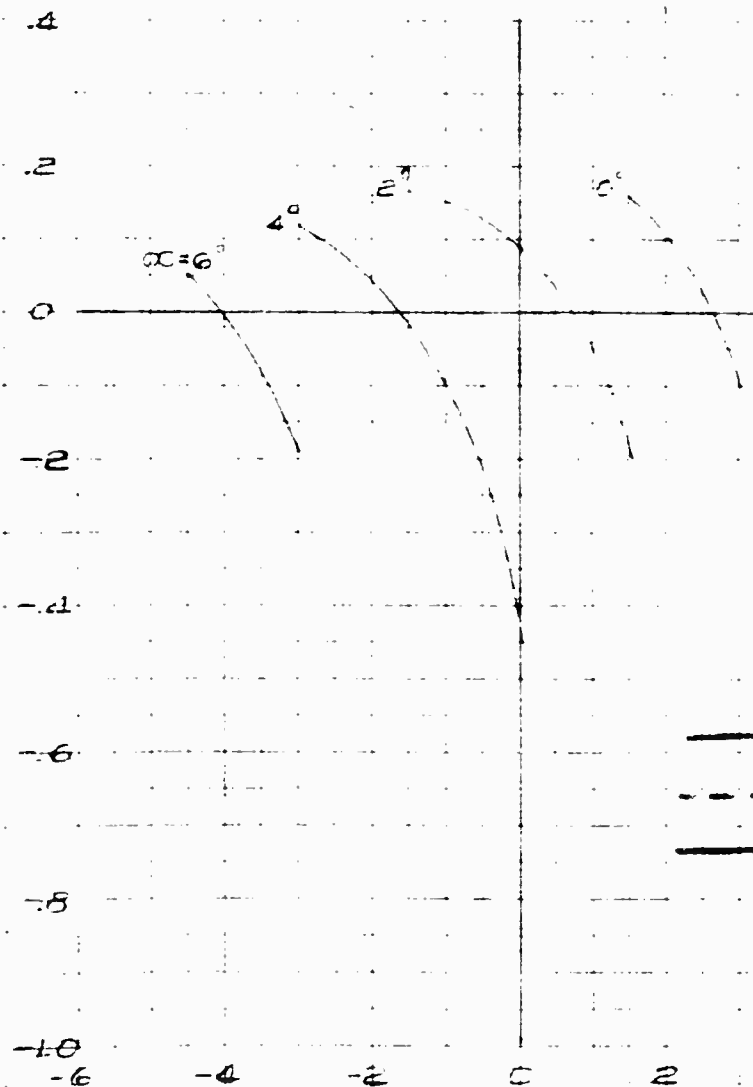
2

4

6

z_0

————— Measured
----- Extrapolated
————— Constant C_0



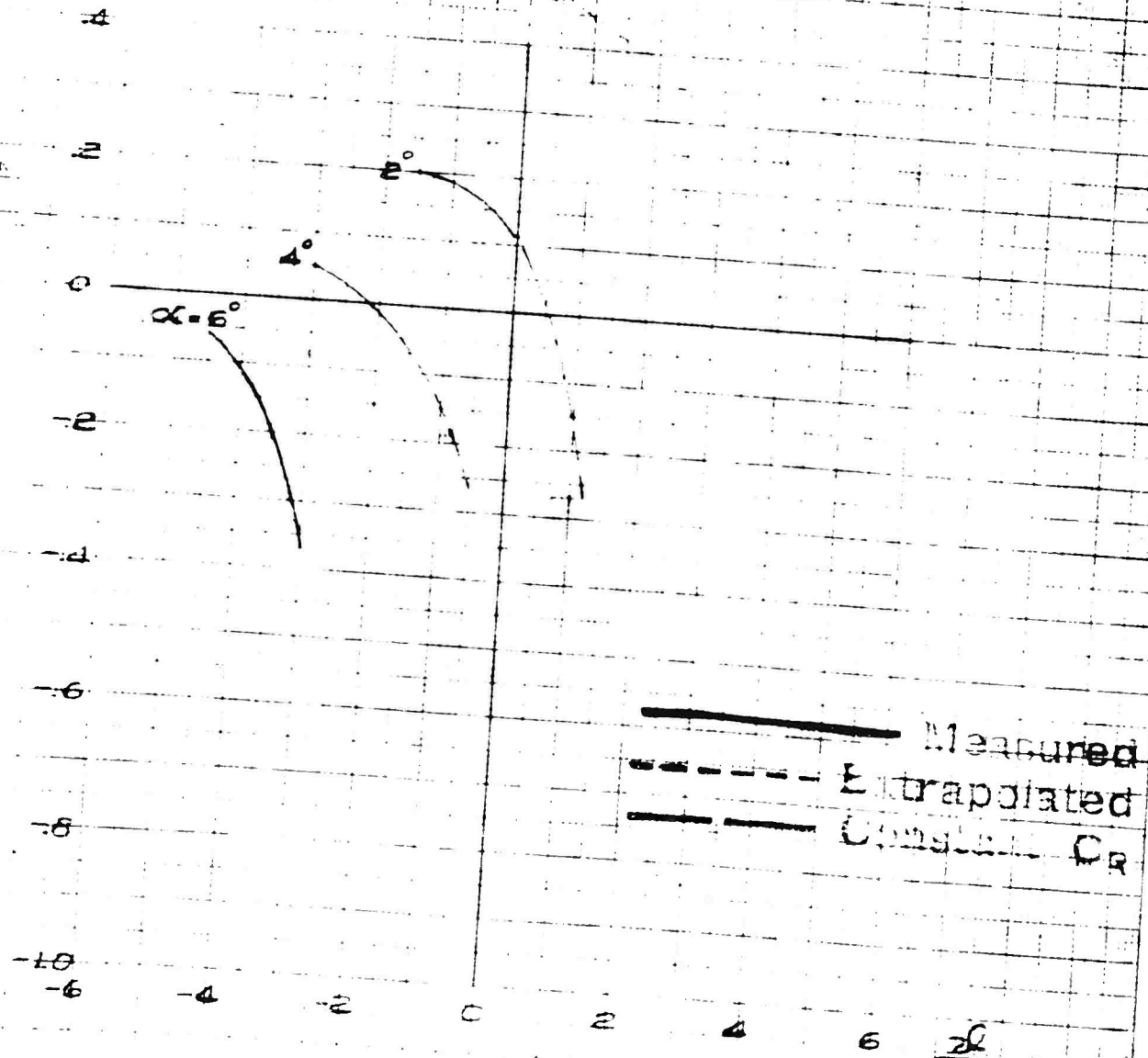
C_D VS z/D

UWAL OCT 49 TESTS
WITHOUT HUB DRAG

B.

11.15

$15^3 C_D$



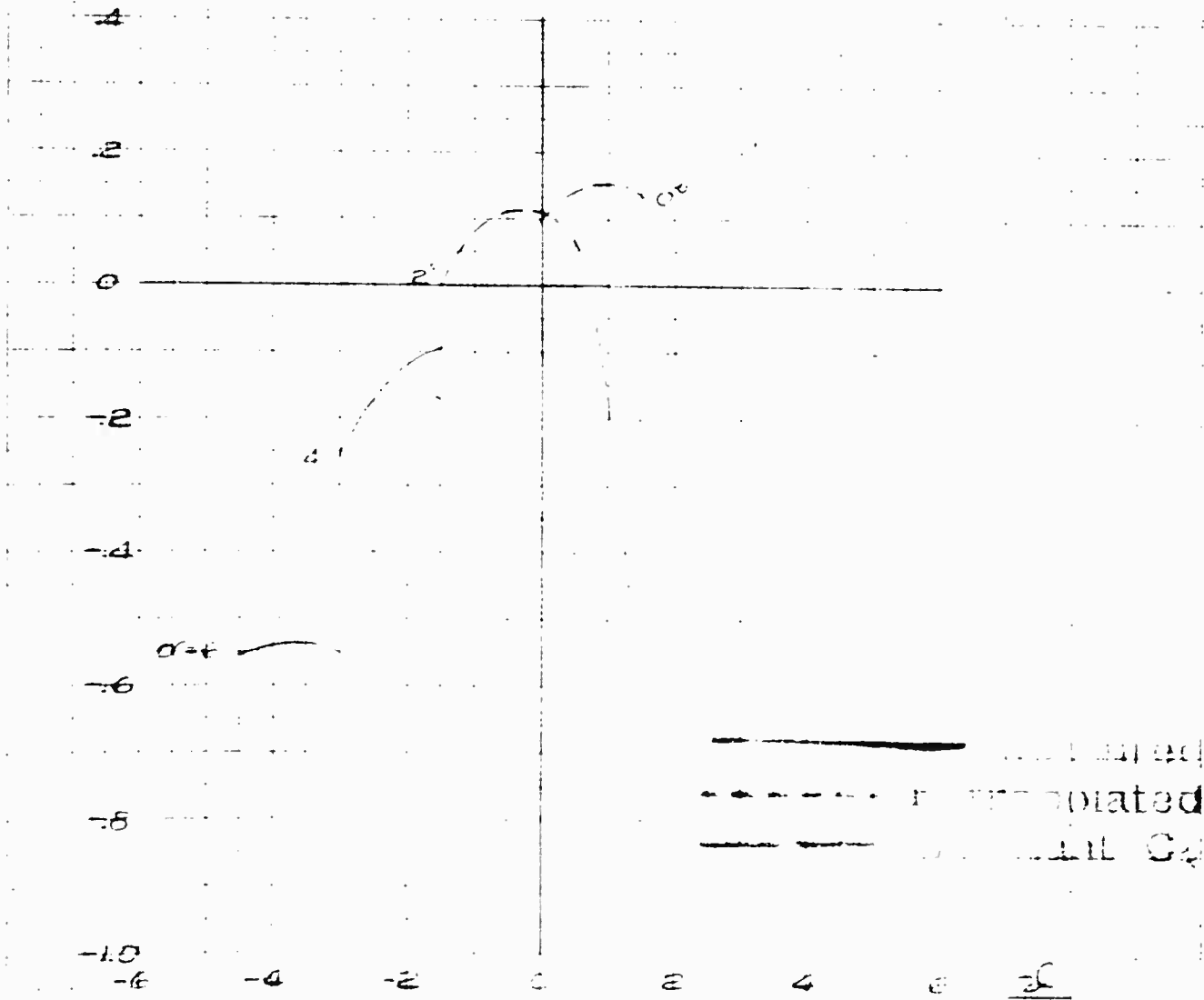
C₀ VS σ

UWAL OCT 49 TESTS
WITHOUT HUB DEAD

E₀

$\mu = 2.0$

$10^3 C_0$



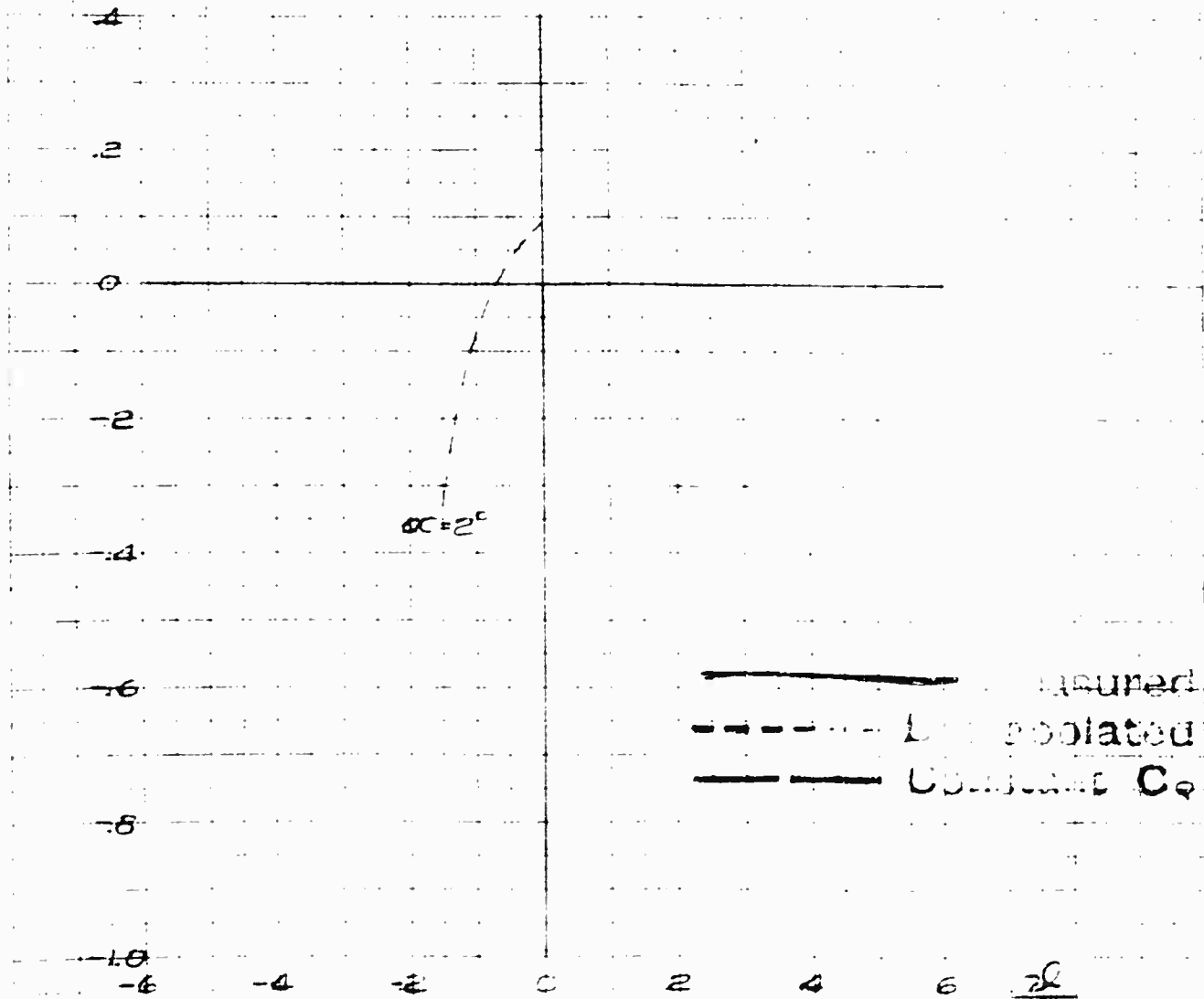
C_0 VS z

UWAL OCT '49 TESTS
WITHOUT HUB DEAD

B_0

$\mu = 2.5$

$10^3 C_0$



Q_1 VS z

UNVAL OCT '45 TESTS
WITHOUT HUB DRAG

B_0

$\mu = .5$

Q_1

10

8

6

4

2

0

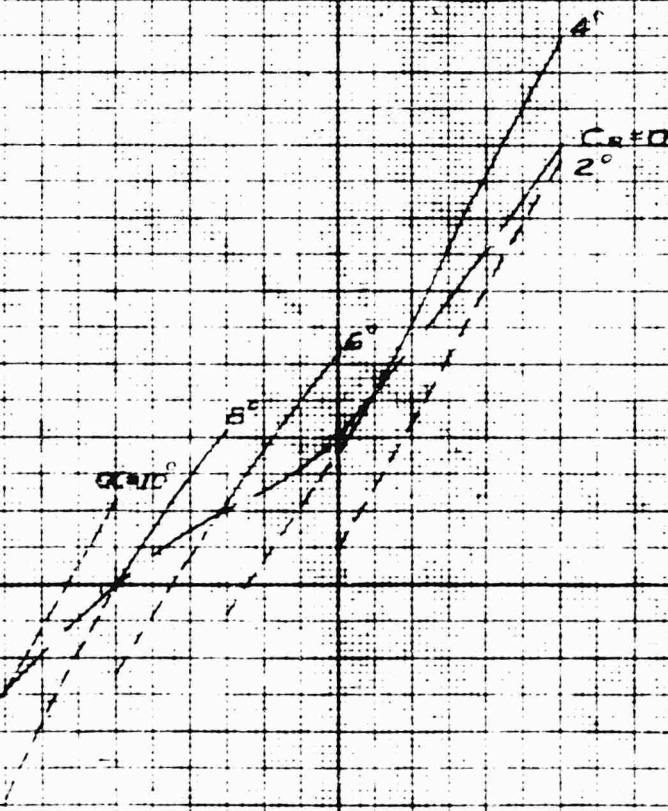
-2

-4

-6

-8

-6



$C_o = 0$

2°

6°

8°

$C_o = 0$

Measured

Extrapolated

Constant C_o

z

Q_1 VS z UNWEIGHTED TESTS
WITHOUT HUE DRAG B_0 $\mu = .75$ Q_1

10

8

6

4

2

0

-2

-4

-6

-8

-6

-4

-2

0

2

4

6

 z

4°

6°

α = 2°

2°

 $C_q = 0$

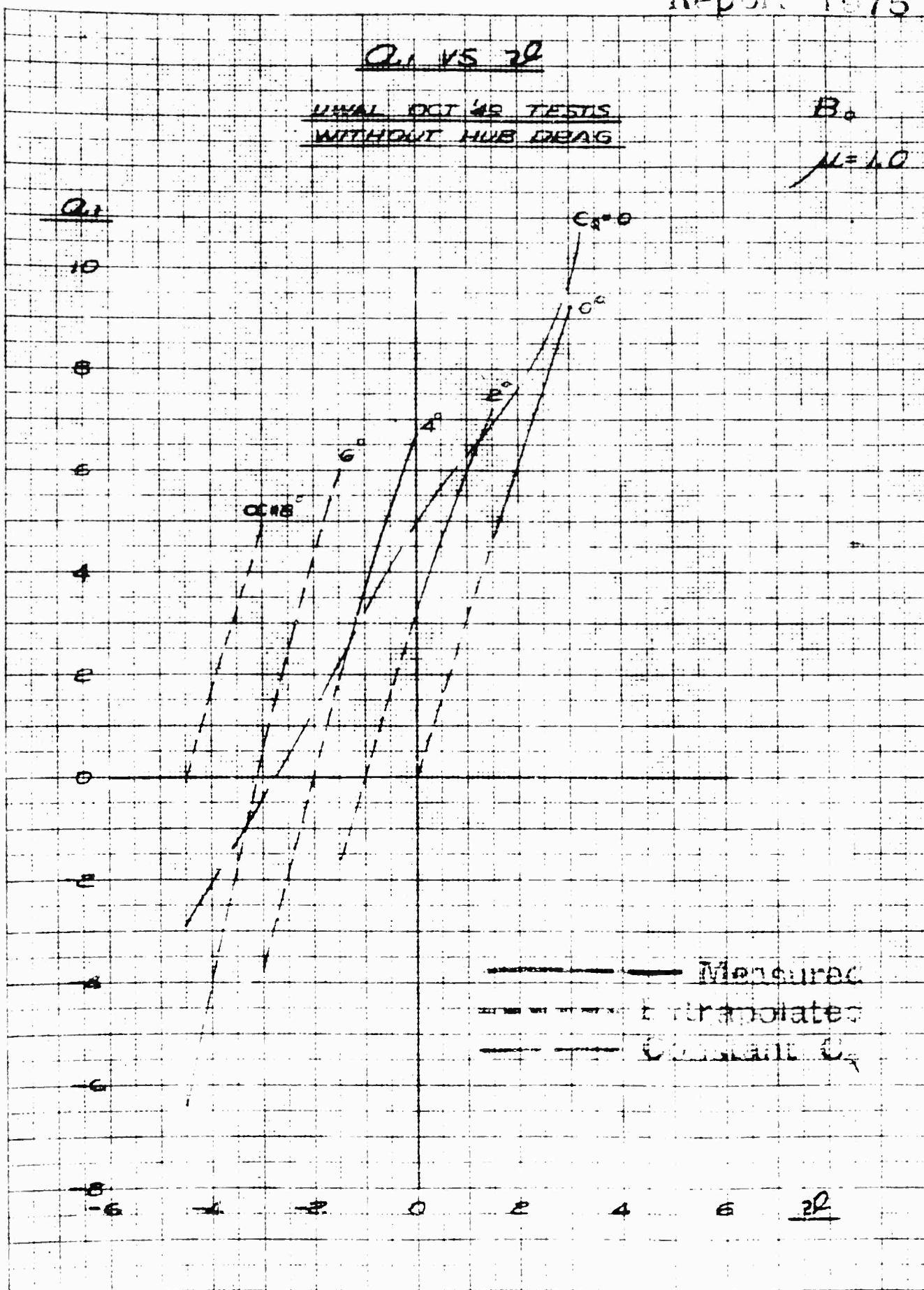
————— Measured
 - - - - - Extrapolated
 ———— Constant C_q

Q_1 VS z

UNVAL OCT '42 TESTS
WITHOUT HUB DRAG

B_0

$\mu = 1.0$



Q_1 VS z_0

UWAL OCT '42 TESTS
WITHOUT HUE DRAG

B_0

$\mu = 125$

Q_1

10

8

6

4

2

0

-2

-4

-6

-8

-6

-4

-2

0

2

4

6

z_0

— Measured
- - - Extrapolated
— Constant C_D

$\alpha = 6^\circ$

$C_D = 0$

4°

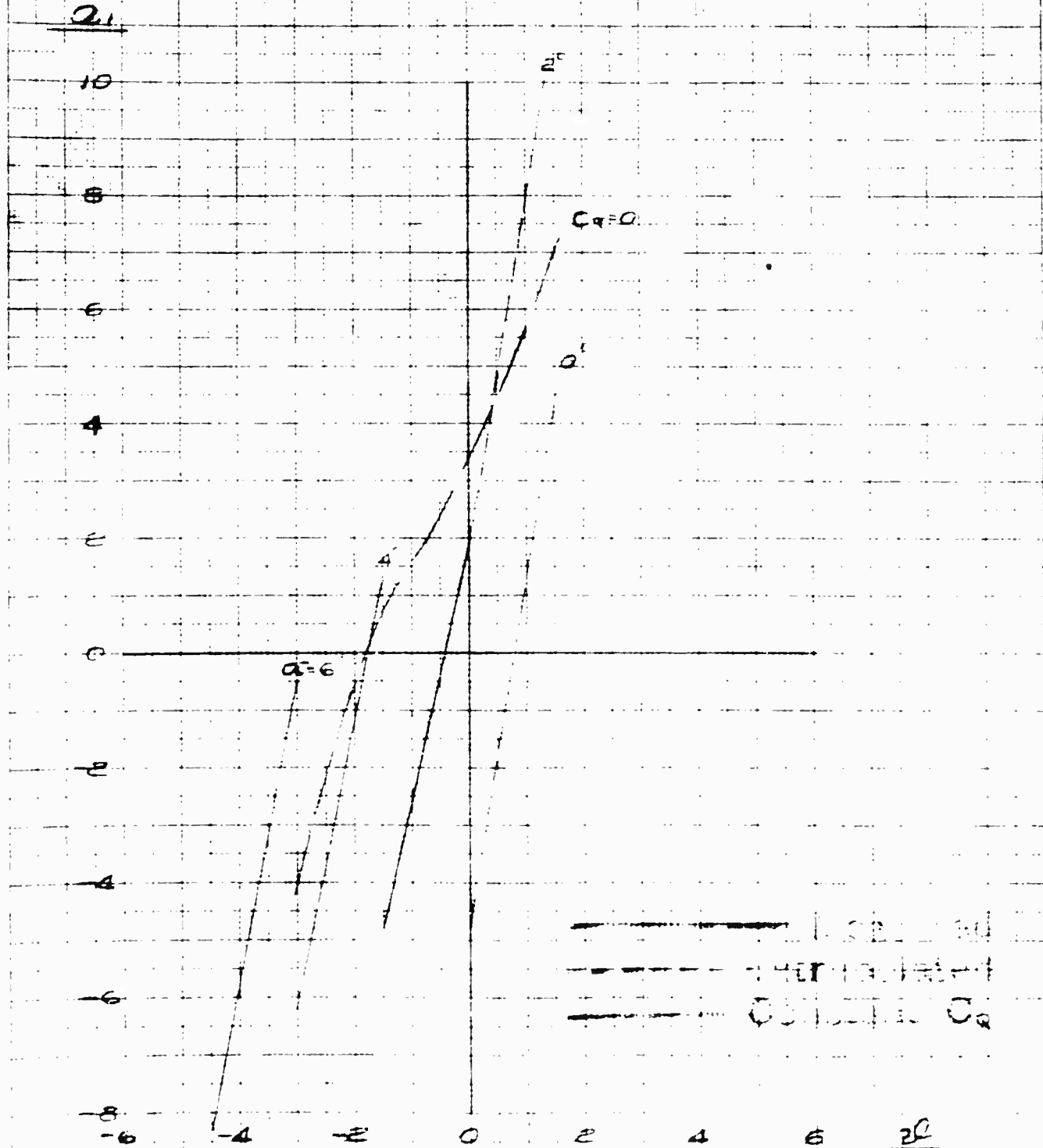
2°

Q₁ VS α

UWAL OCT 49 TESTS
WITHOUT HUE DRAG

B_c

$\mu = 1.5$



Q_1 VS z_0 UWAL OCT '45 TESTS
WITHOUT HUE DRAG B_c $W.P.C$ Q_1

10

5

4

3

2

1

0

-1

-2

-3

-6

-4

-2

0

2

4

6

 z_0 z' 4° $\alpha = 6^\circ$ $C_d = 10$ 10°

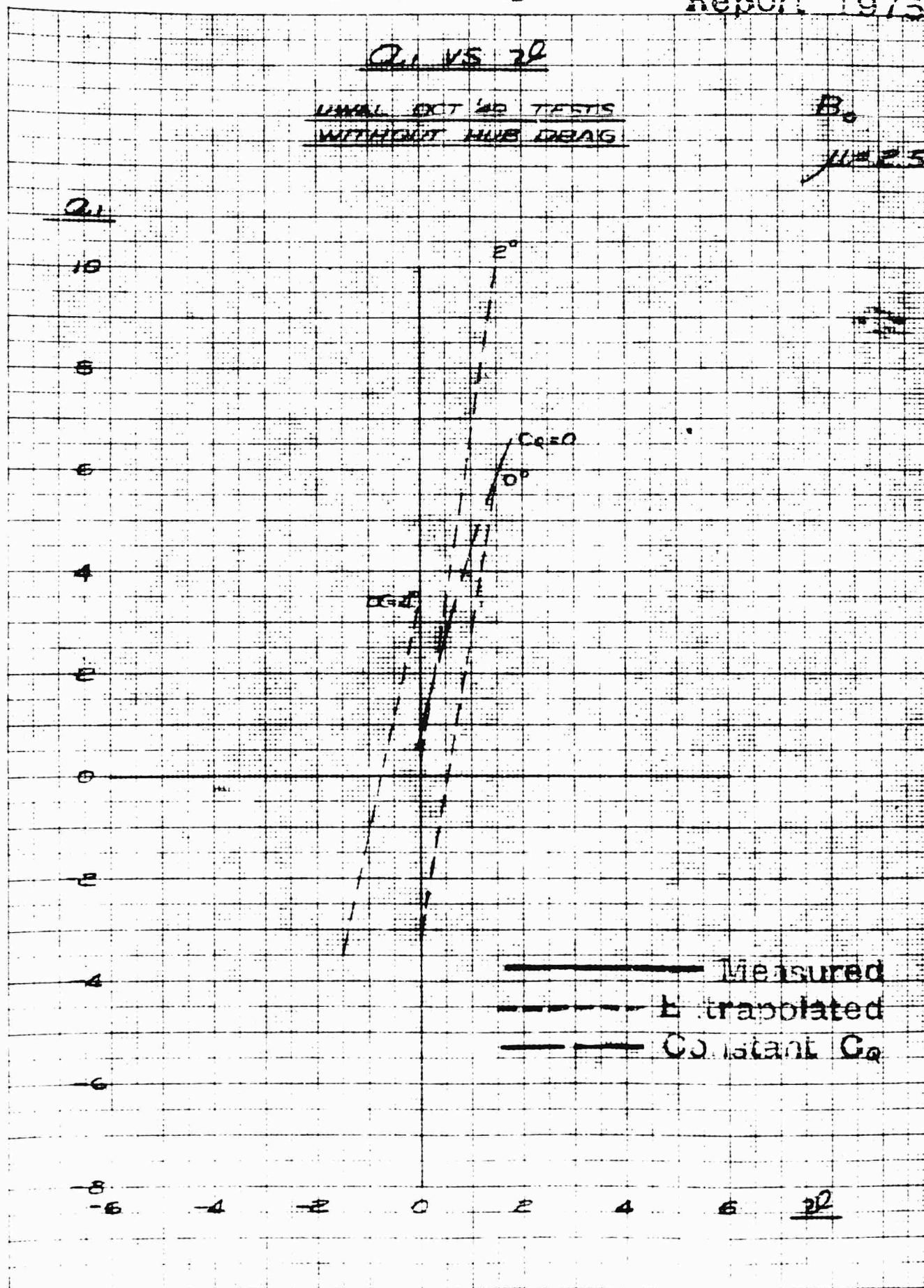
————— Measured
 - - - - - Extrapolated
 ———— Constant C_d

Q. VS 20

UNHAL EXT 40 TESTS
WITHOUT HUB DRAG



11225



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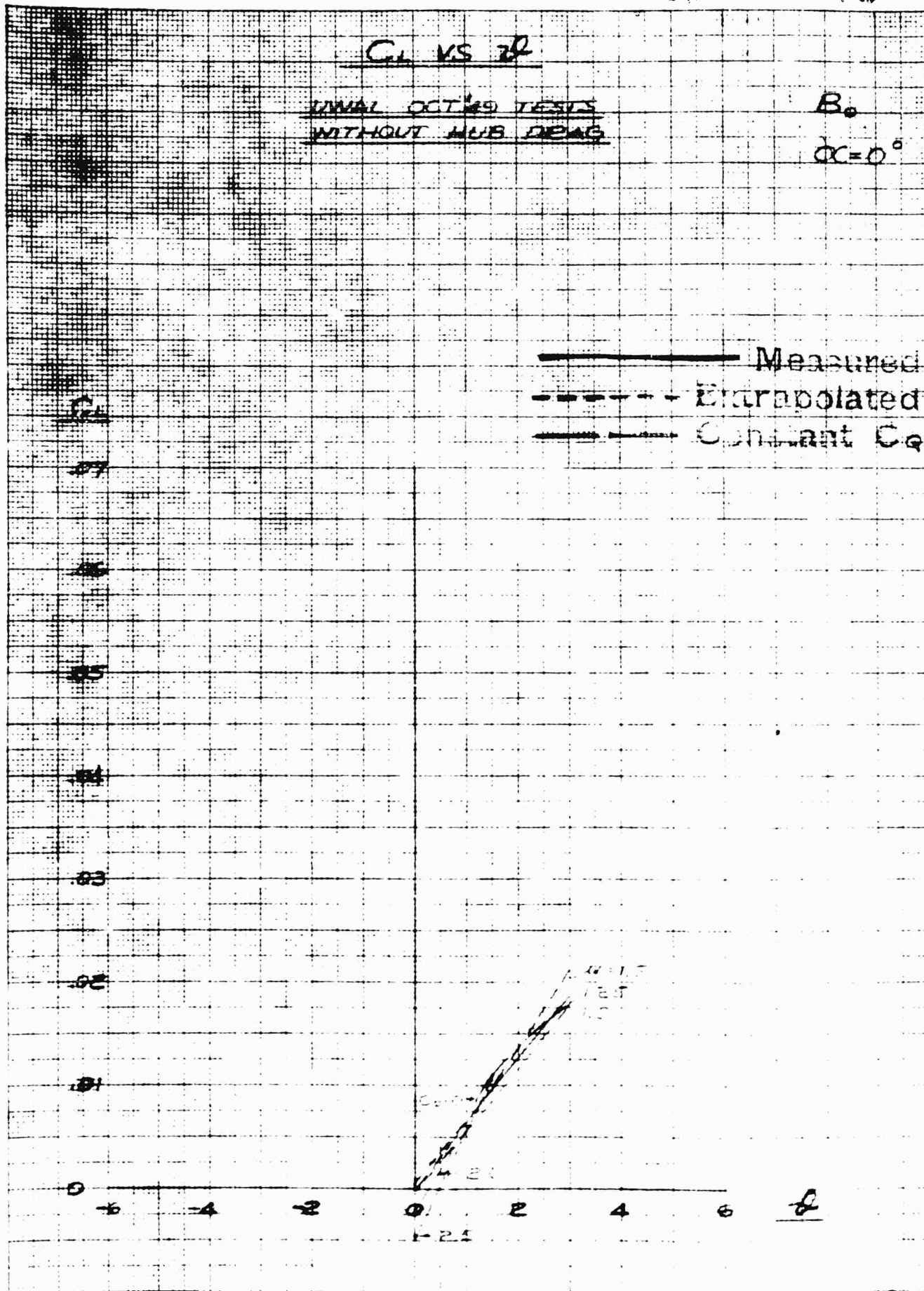
C_L VS α

UNVAL OCT 49 TESTS
WITHOUT HUB DRAG

B_0

$\alpha = 0^\circ$

— Measured
- - - Extrapolated
— Constant C_q



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Report 1075

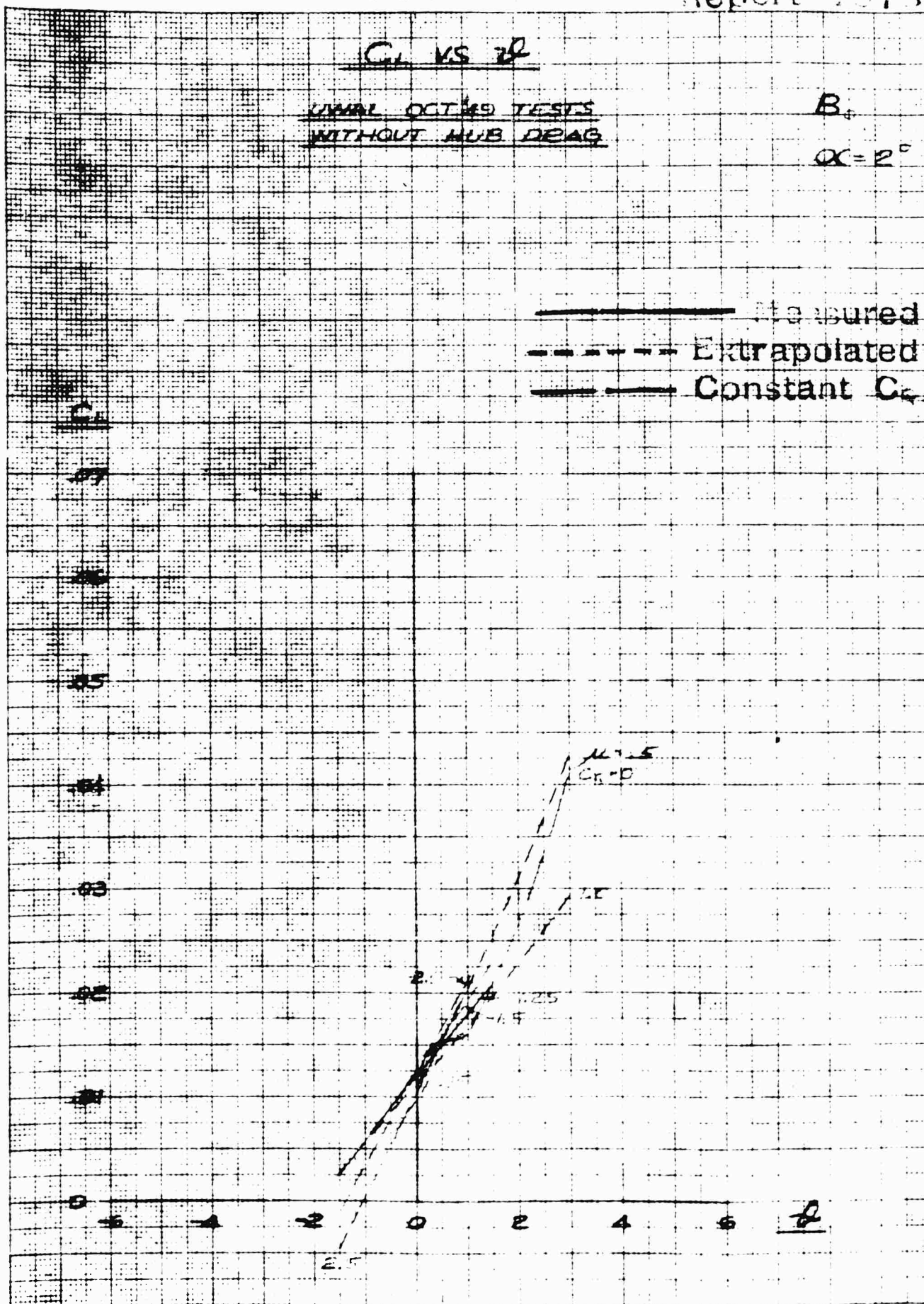
C_L VS ϕ

UNAL OCT 49 TESTS
WITHOUT HUB DEAG

B_0

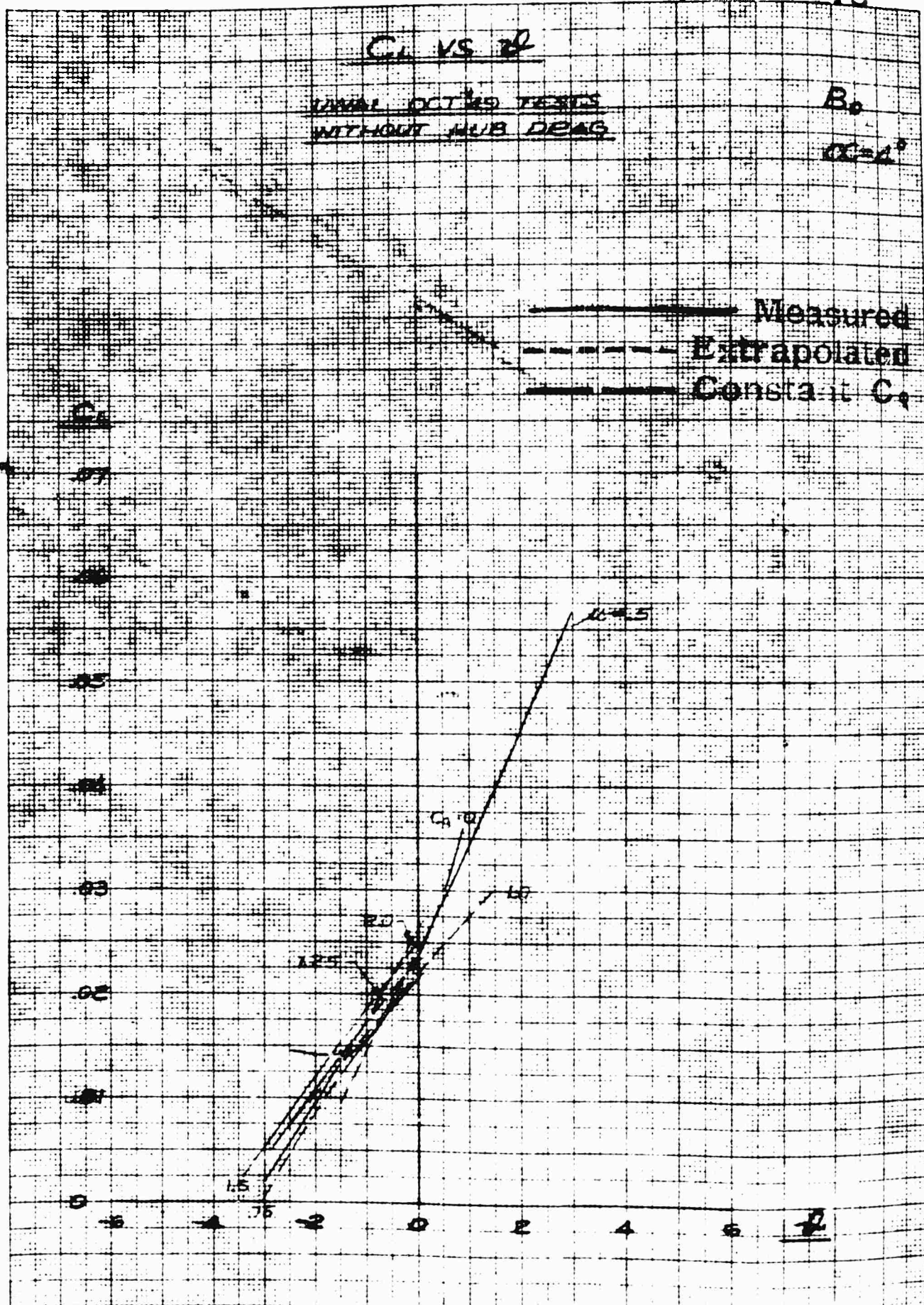
$\alpha = 2^\circ$

———— Measured
----- Extrapolated
———— Constant C_0



KEUFFEL & ESSER CO.

No. 359 14 Millimeters, 5 mm lines spaced, cm lines heavy



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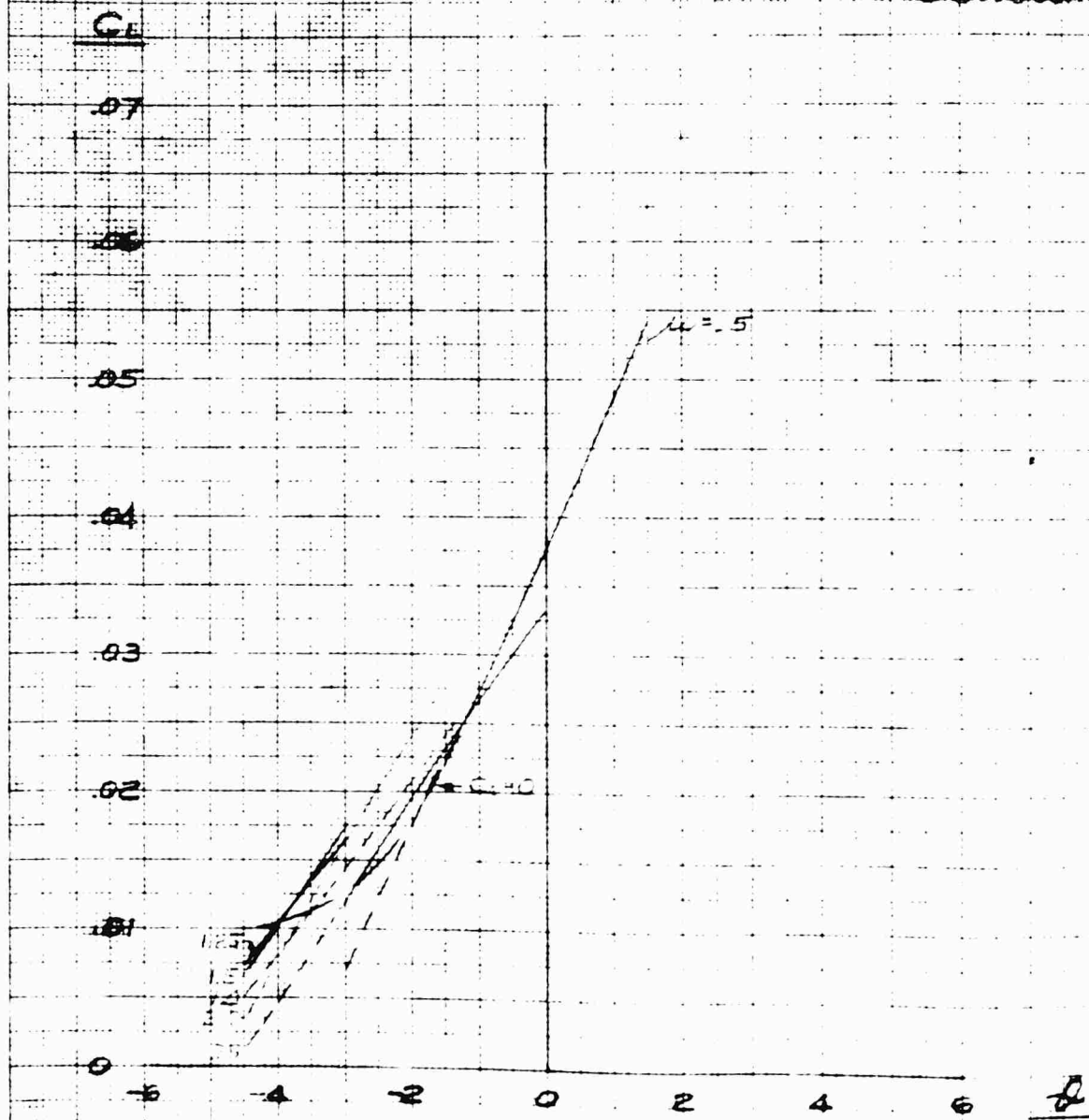
CL VS α

UWAL OCT '49 TESTS
WITHOUT HLB DRAG

B_0

$\alpha = 6^\circ$

————— Measured
----- Extrapolated
————— Constant C_s



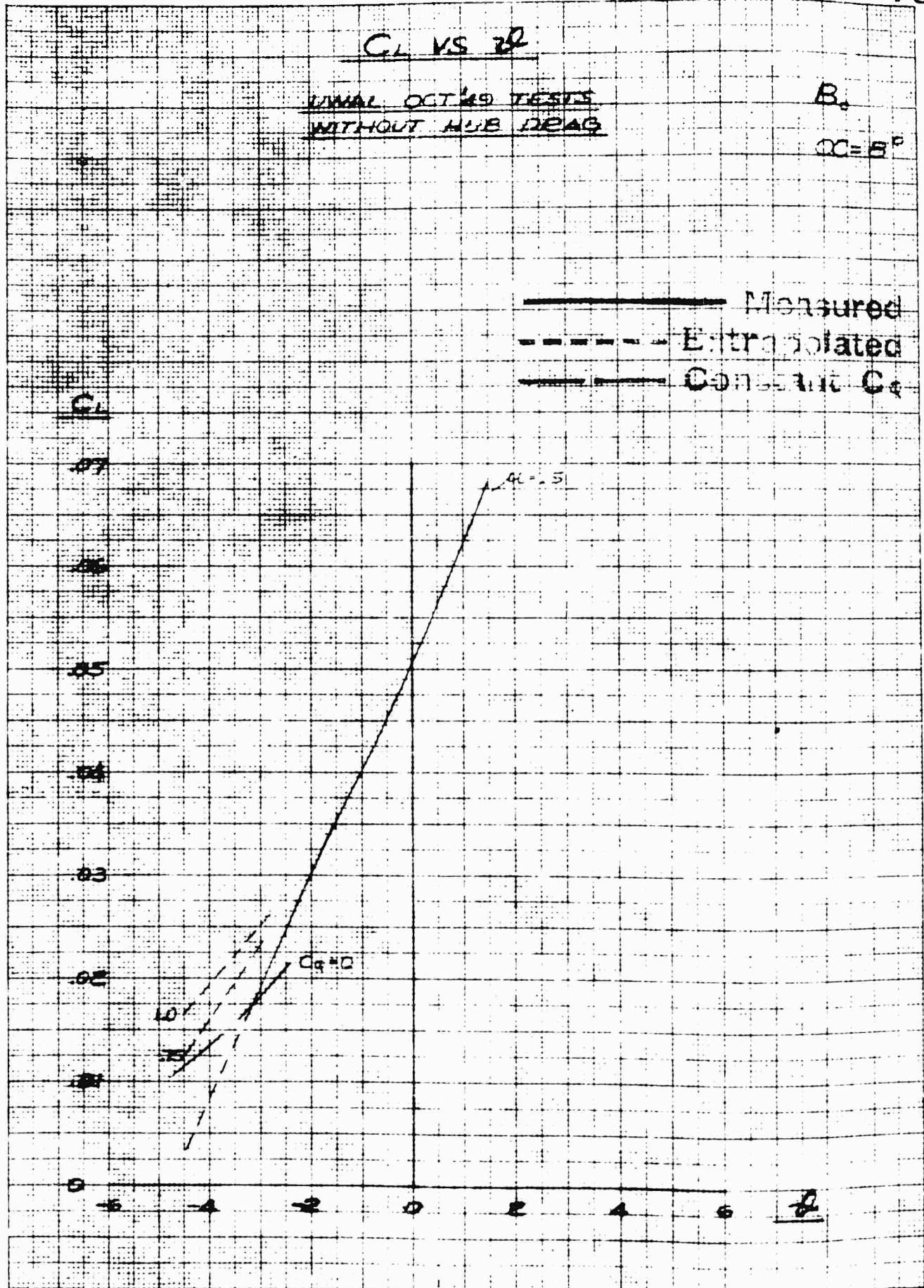
CL VS ϕ

UNIAL OCT 49 TESTS
WITHOUT HUB DRAG

B.

$\alpha = 5^\circ$

————— Measured
----- Extrapolated
————— Constant C_d



C_T VS $2C$ $10^3 C_T$ UNAL OCT '49 TESTS
WITHOUT HUB DRAG B_0 $OC = 0^\circ$

40

36

32

28

24

20

16

12

8

4

0

-6

-4

-2

0

2

4

6

 $2C$

1.2 E

2.0

 $C_s = 0$

1.5

1.05

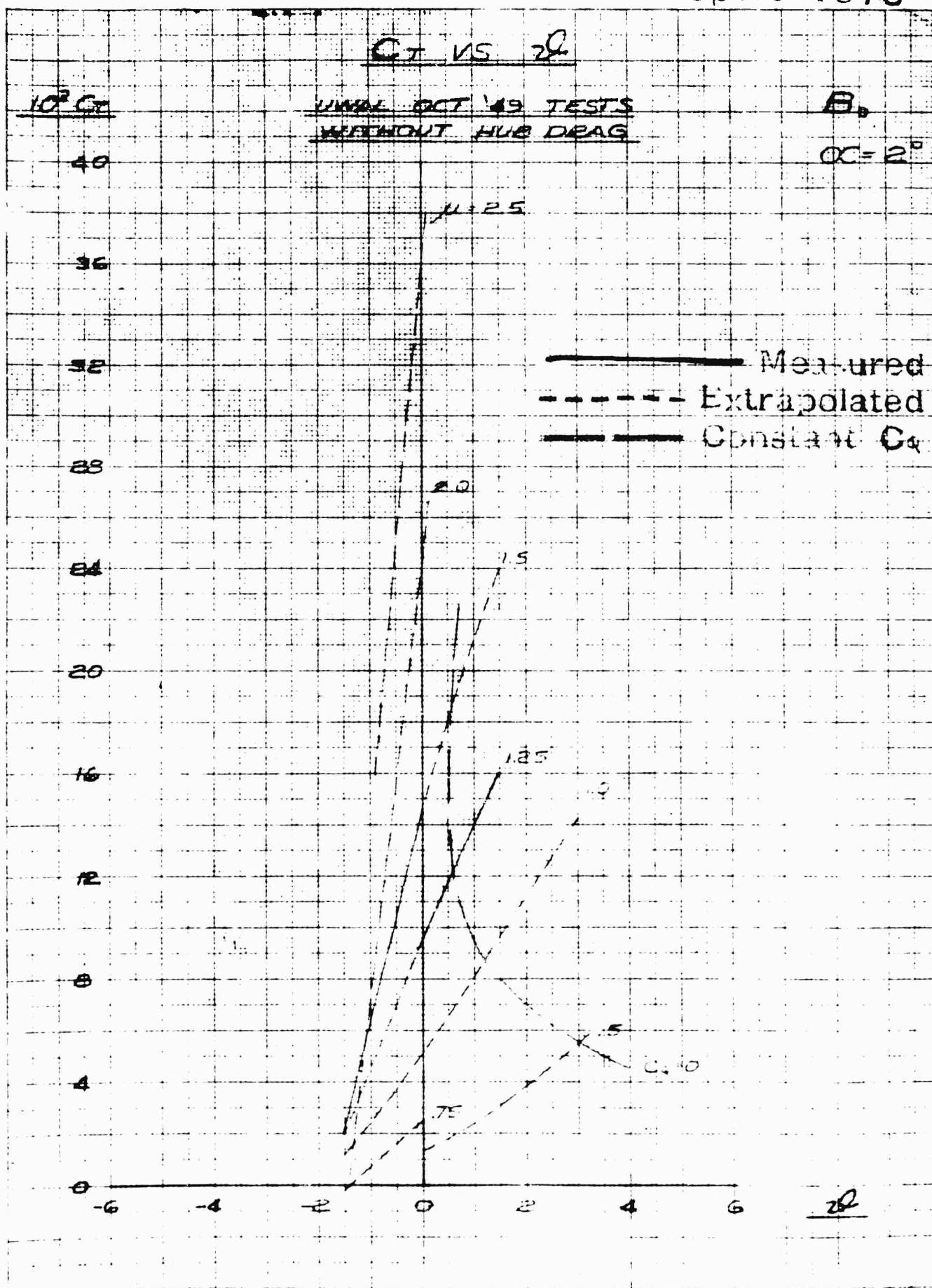
1.0

— Measured
 - - - - - Interpolated
 ———— Constant C_s

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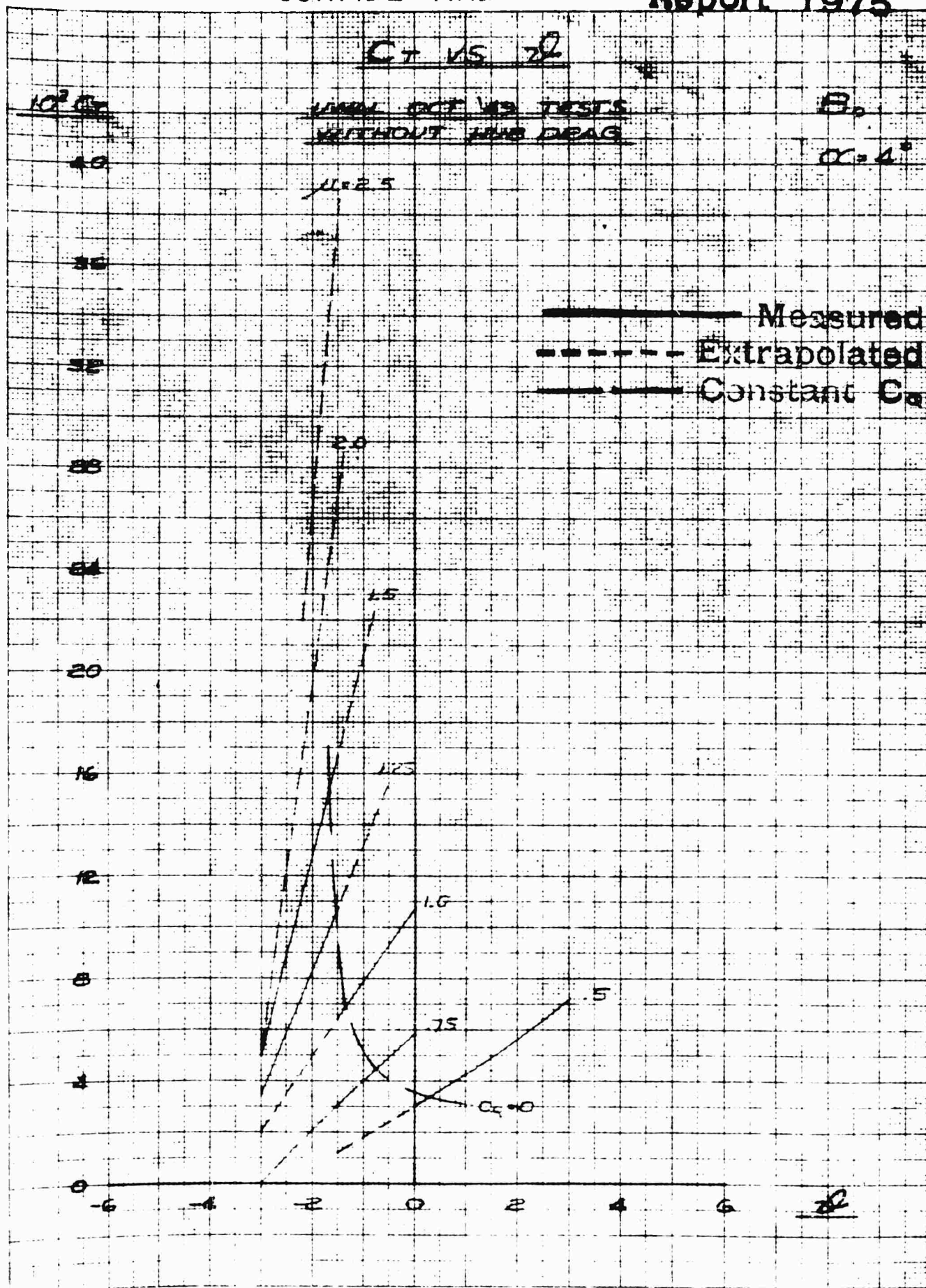
246

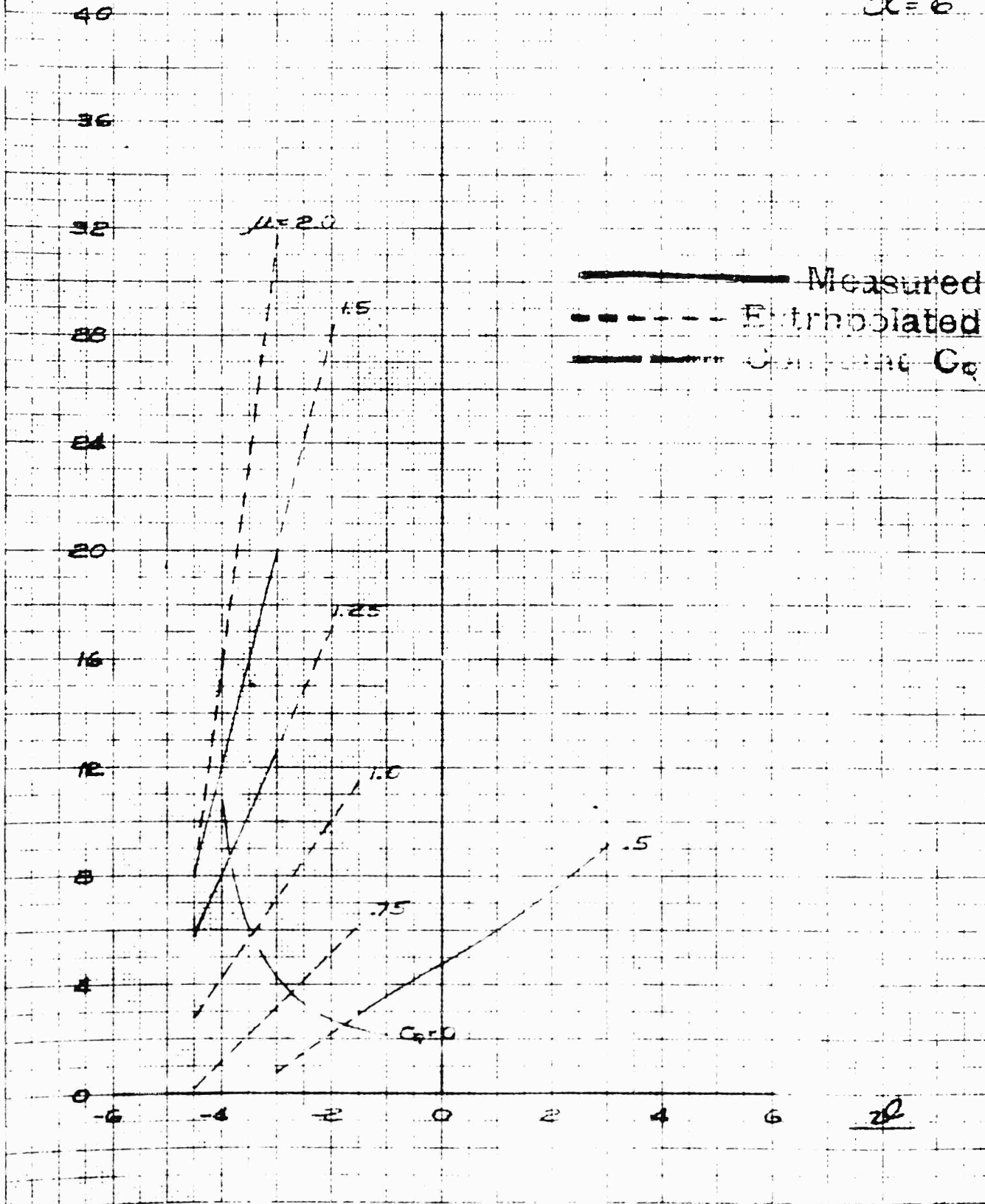
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C_T VS z $10^3 C_T$ UNVAL OCT '49 TESTS
WITHOUT HUB DRAG B_0 $\alpha = 6^\circ$ 

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C_T VS z

$10^3 C_T$

UNIV. OCT '49 TESTS
WITHOUT HUB DRAG

B_p

$OC = B^p$

40

36

32

28

24

20

16

12

8

4

0

-6

-4

-2

0

2

4

6

z

Measured
Extrapolated
Constant C_q

$1/\mu = 1.25$

1.0

.75

.5

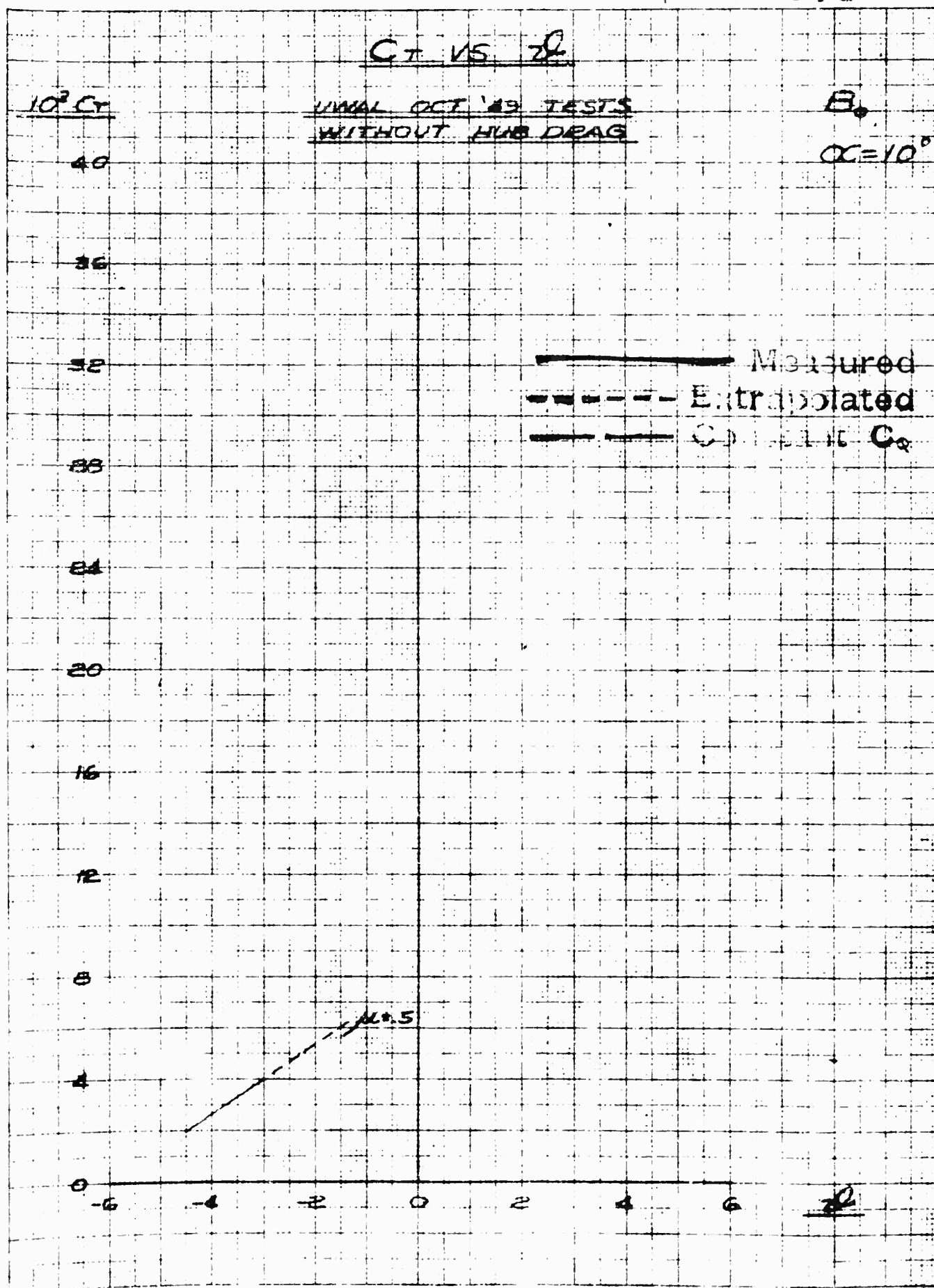
$C_q = 0$

KEUFFEL & ESSER CO.

No. 317314. Millimeters, 5 mm by 10 mm, 10 mm by 10 mm, 10 mm by 10 mm.

CONFIDENTIAL

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KEUFEL & ESSER CO.

No. 31914 Millimeters 5 mm units included in times heavy

CONFIDENTIAL

E2
10.19

C_D vs. β
UNAL OCT 49 TESTS
WITHOUT INB DFRG

B_c

$\alpha = 0^\circ$

C_D

.010

.009

.008

.007

.006

.005

.004

.003

.002

.001

0

-4

-2

0

2

4

6

β

$\alpha = 1.0$

$C_R = 0$

1.25

1.5

20

Measured

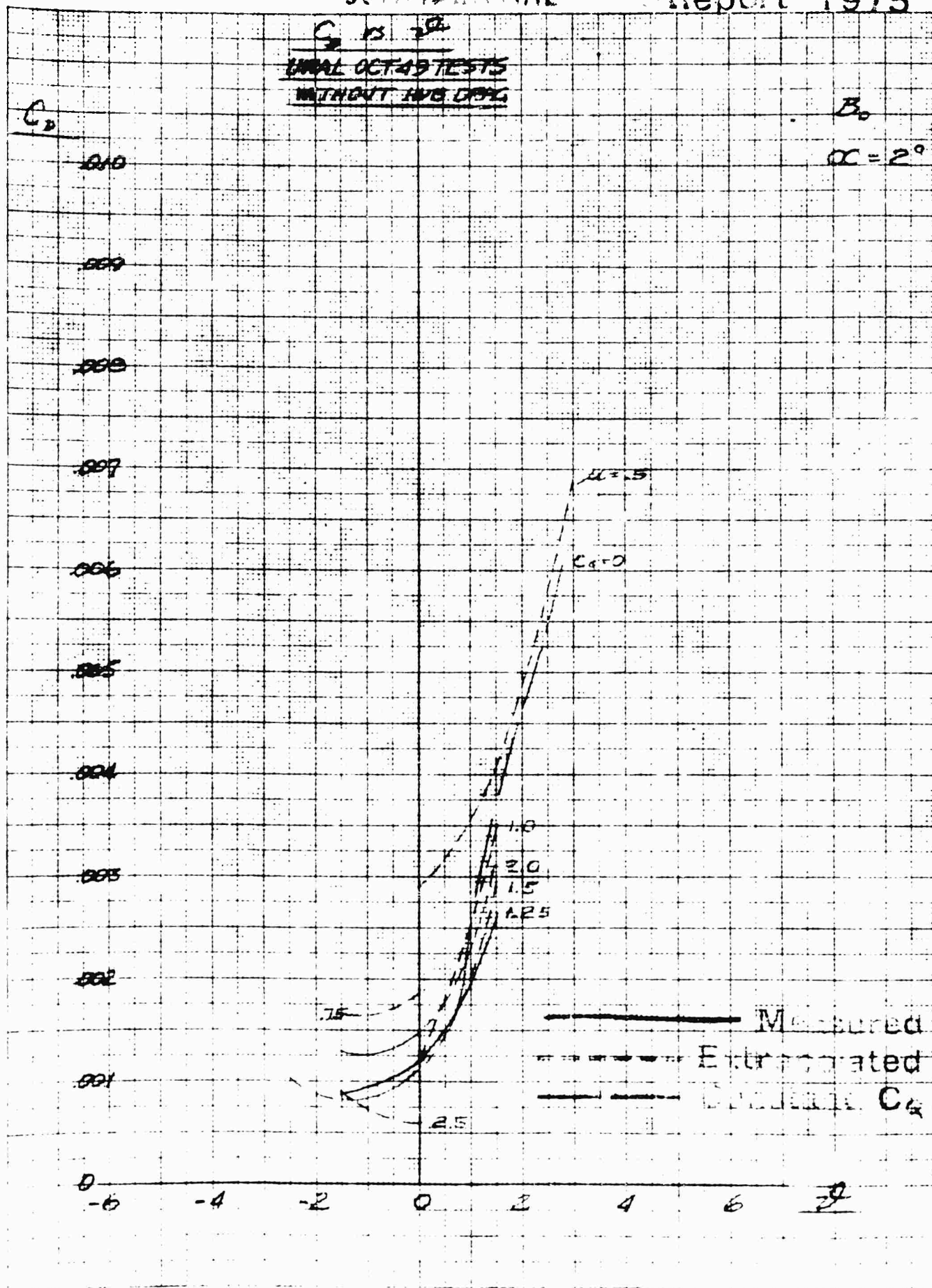
Extrapolated

$C_{D, \text{min}} C_q$

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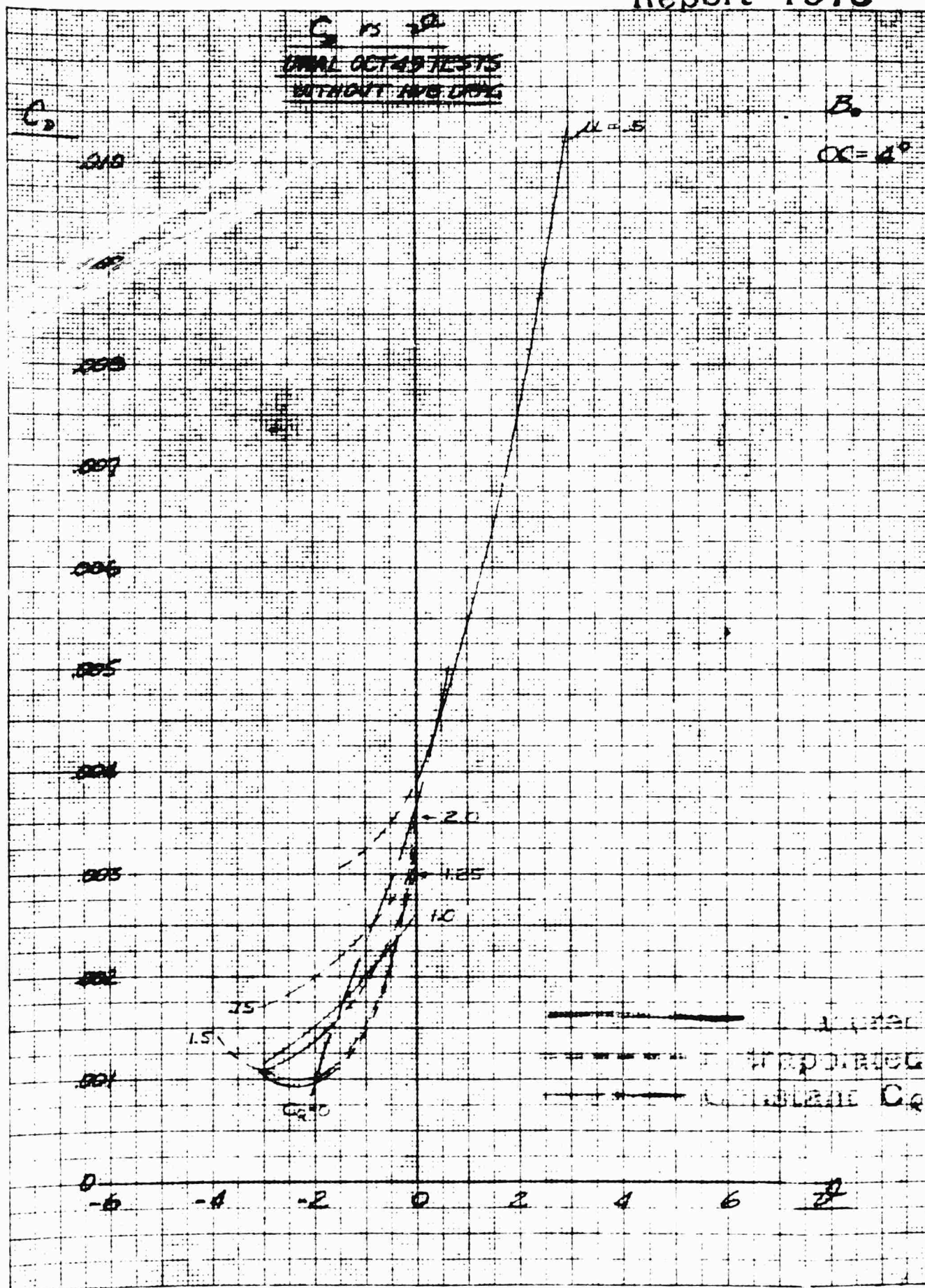
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C_p vs β
UNAL OCT 49 TESTS
WITHOUT FIVE DPG



Report ⁴²³ 1975

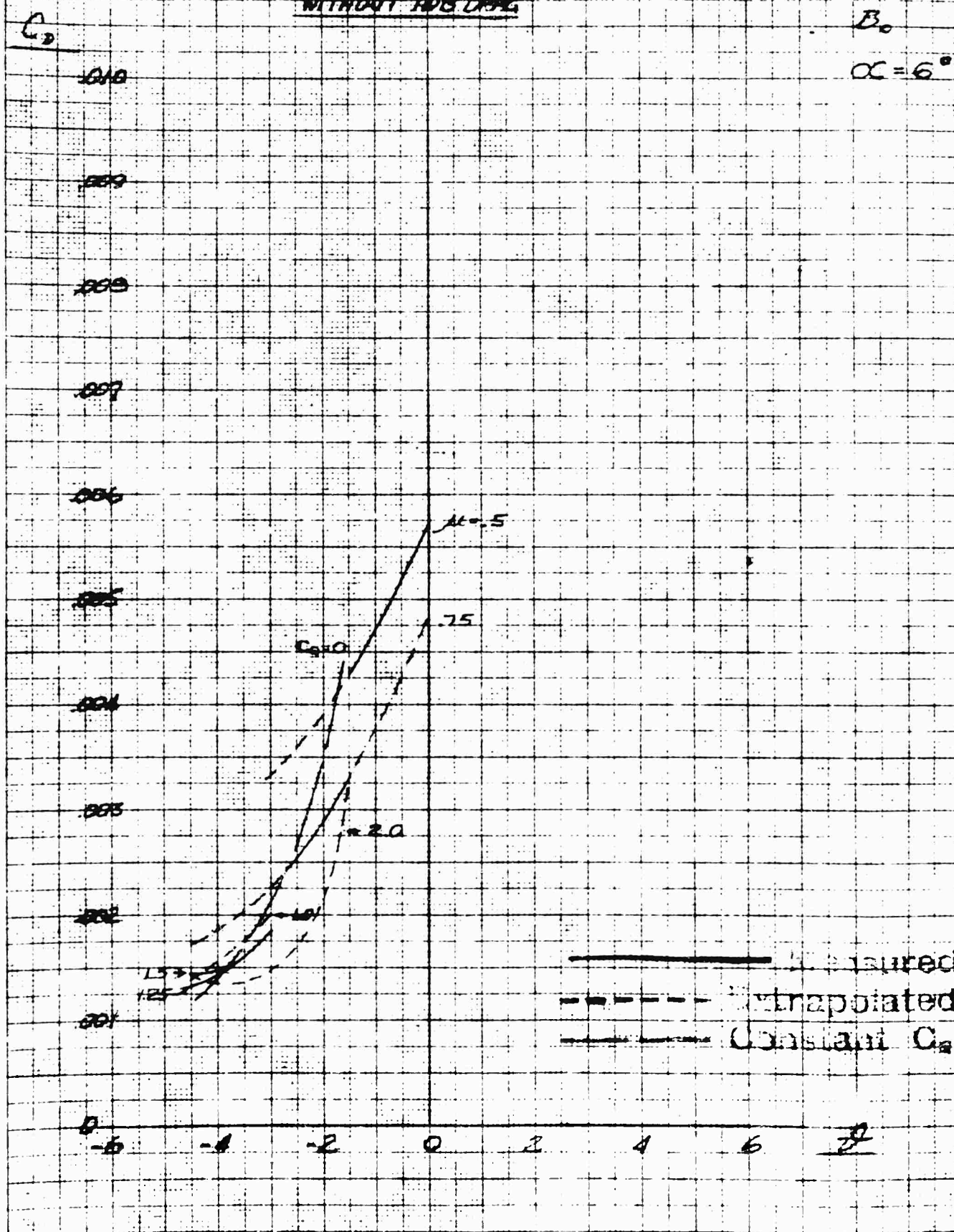
Report T975



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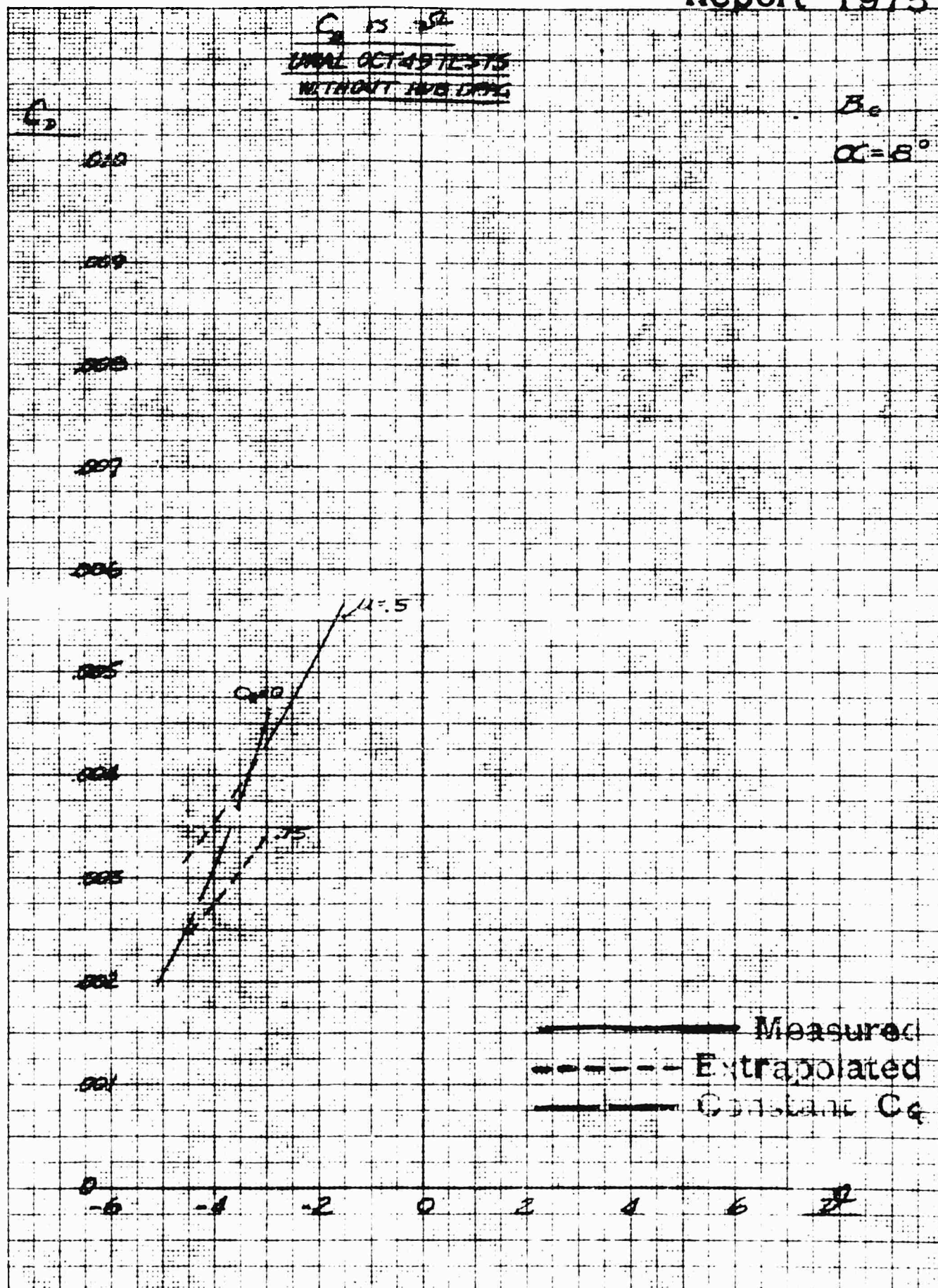
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C_2 is 2
INITIAL OCT 49 TESTS
WITHOUT HUB DRAG



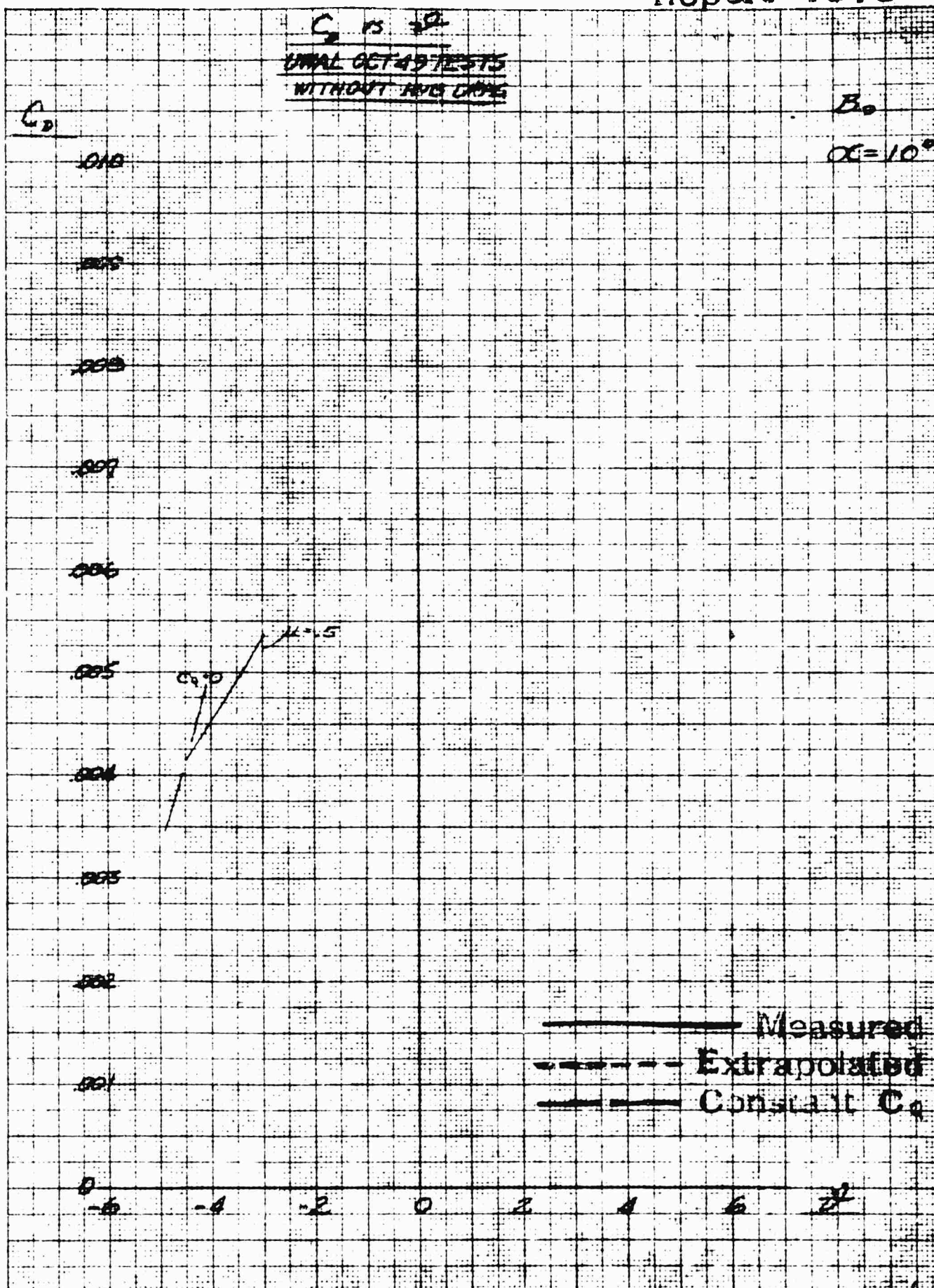
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KEUFFEL & ESSER CO.

No. 359-14. Millimeters, 5 mm lines are centred, cm lines heavy

CONFIDENTIAL

28-21
17-10-07

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L/D vs θ

LOCAL OCT 45 TESTS
WITHOUT HUB DRAG

B_0

$\alpha = 0^\circ$

————— Measured
----- Extrapolated
----- Constant C_r

L/D

C_{R0}

11.5

12.5

1.0

-6 -4 -2 0 2 4 6 θ

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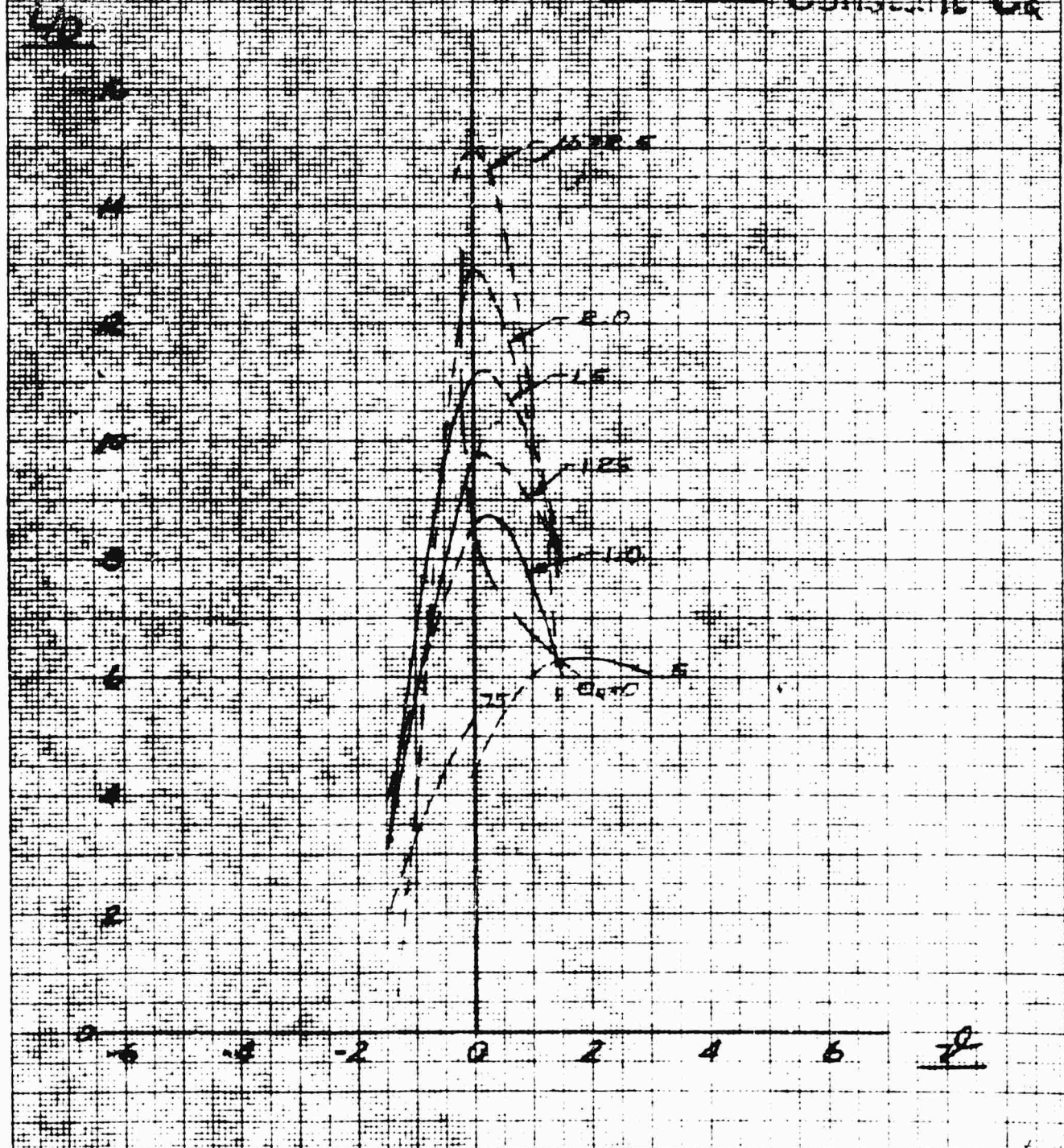
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4.0 in 2
UNAL OCT 45 TESTS
WITHOUT HUB DATA

B.

$\alpha = 2^\circ$

———— Measured
----- Extrapolated
———— Constant C_k



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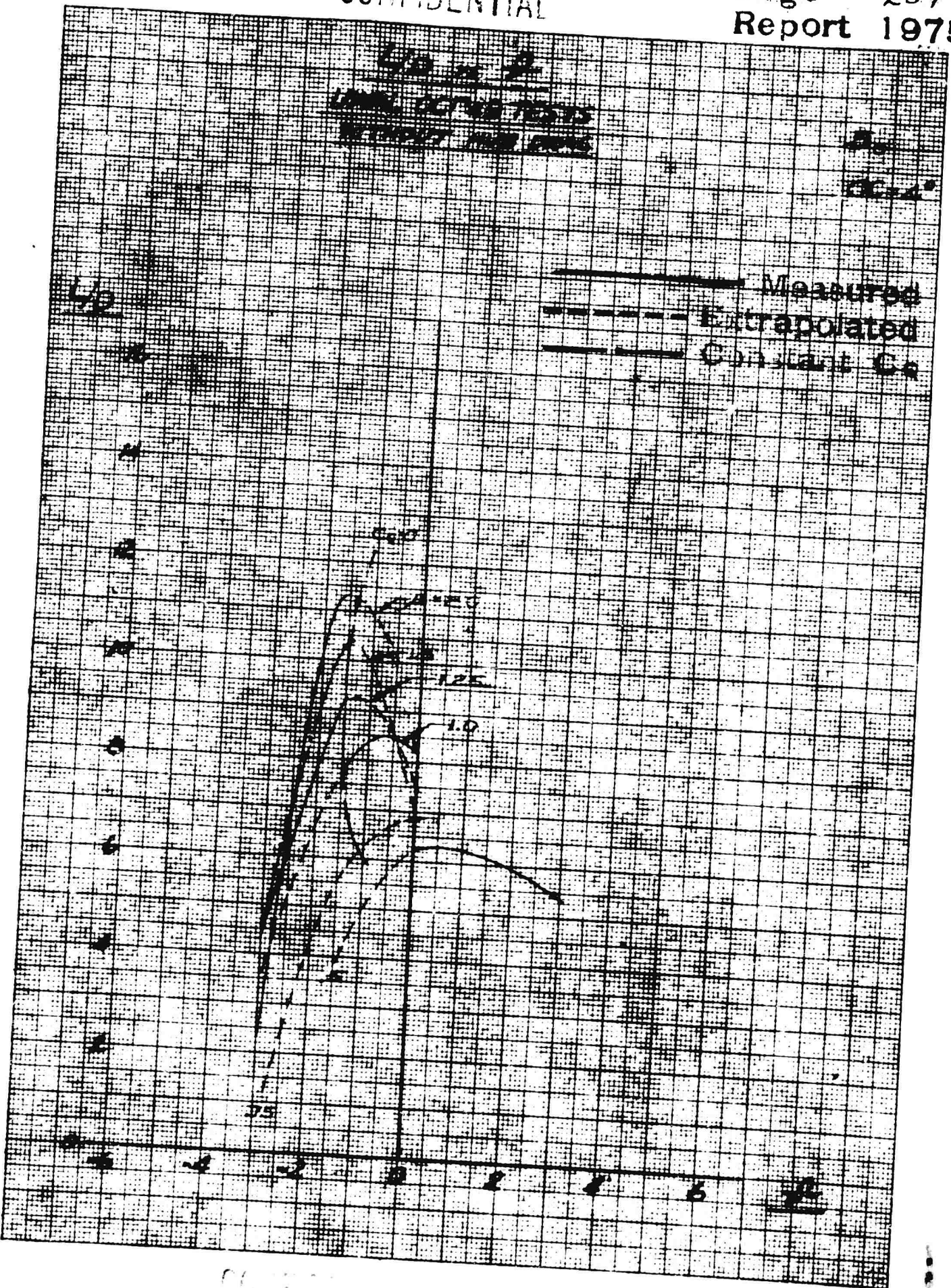
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U₀ = 2
UNION OCT 28 TESTS
RETRACT 1000 PSI

20
1000

U₀

Measured
Extrapolated
Constant C₀



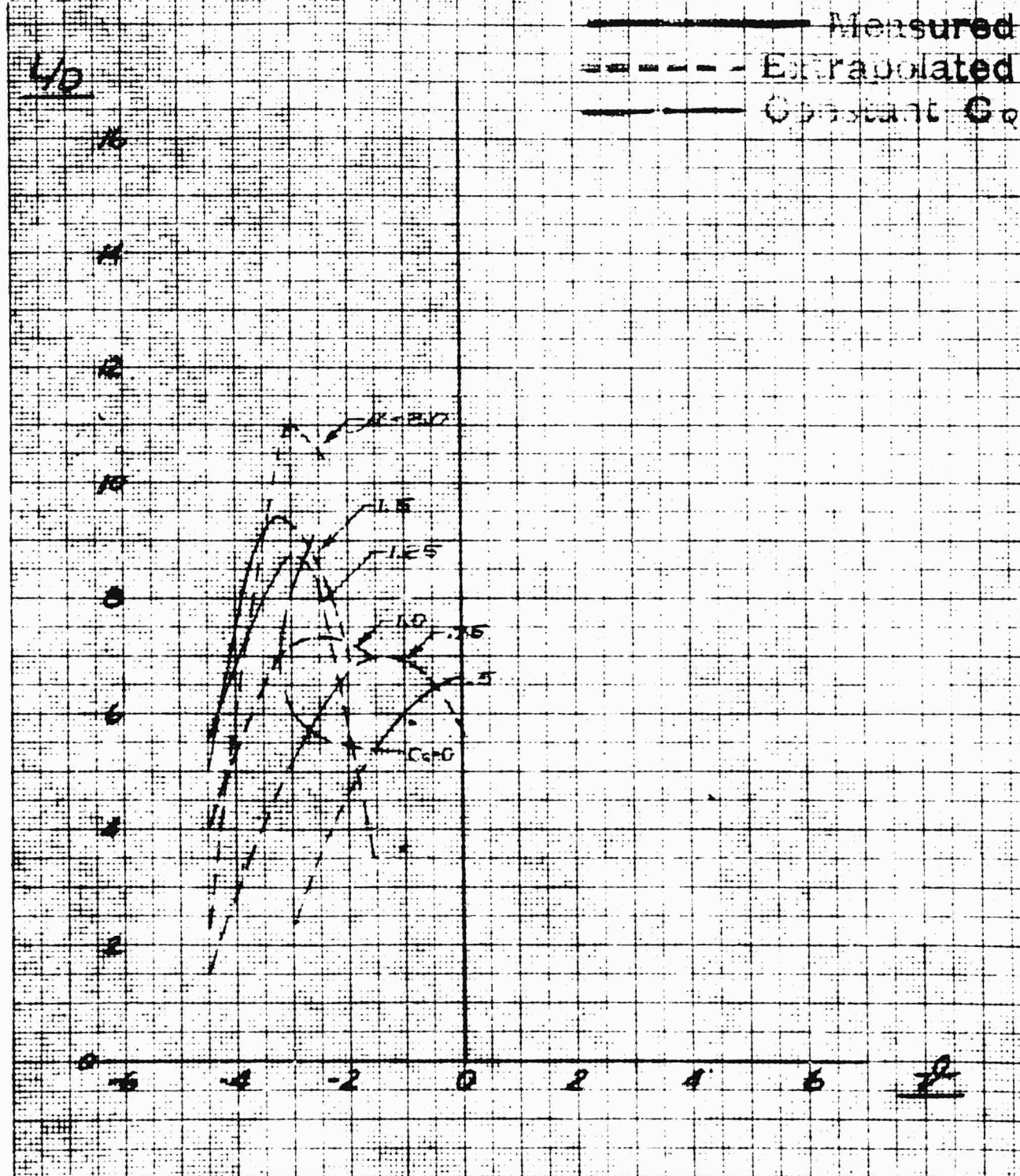
KEUFFEL & ESSER CO.

No. 898-16. Millimeter, 5 mm lines spaced, cm lines heavy.

12-10-49

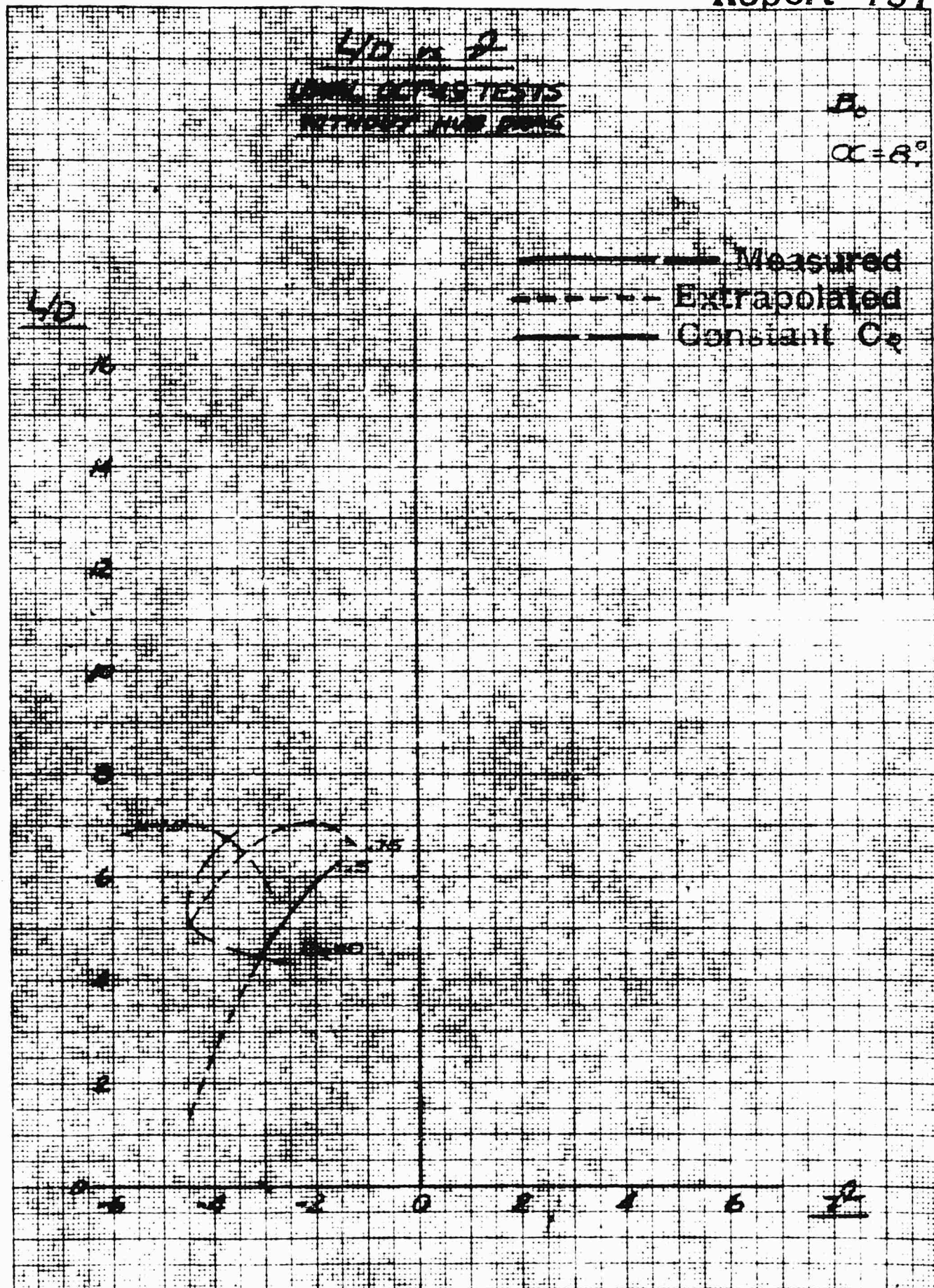
L/D is 2
UNIV. OCT 49 TESTS
WITHOUT HUB DRAG

B.
 $\alpha = 6^\circ$



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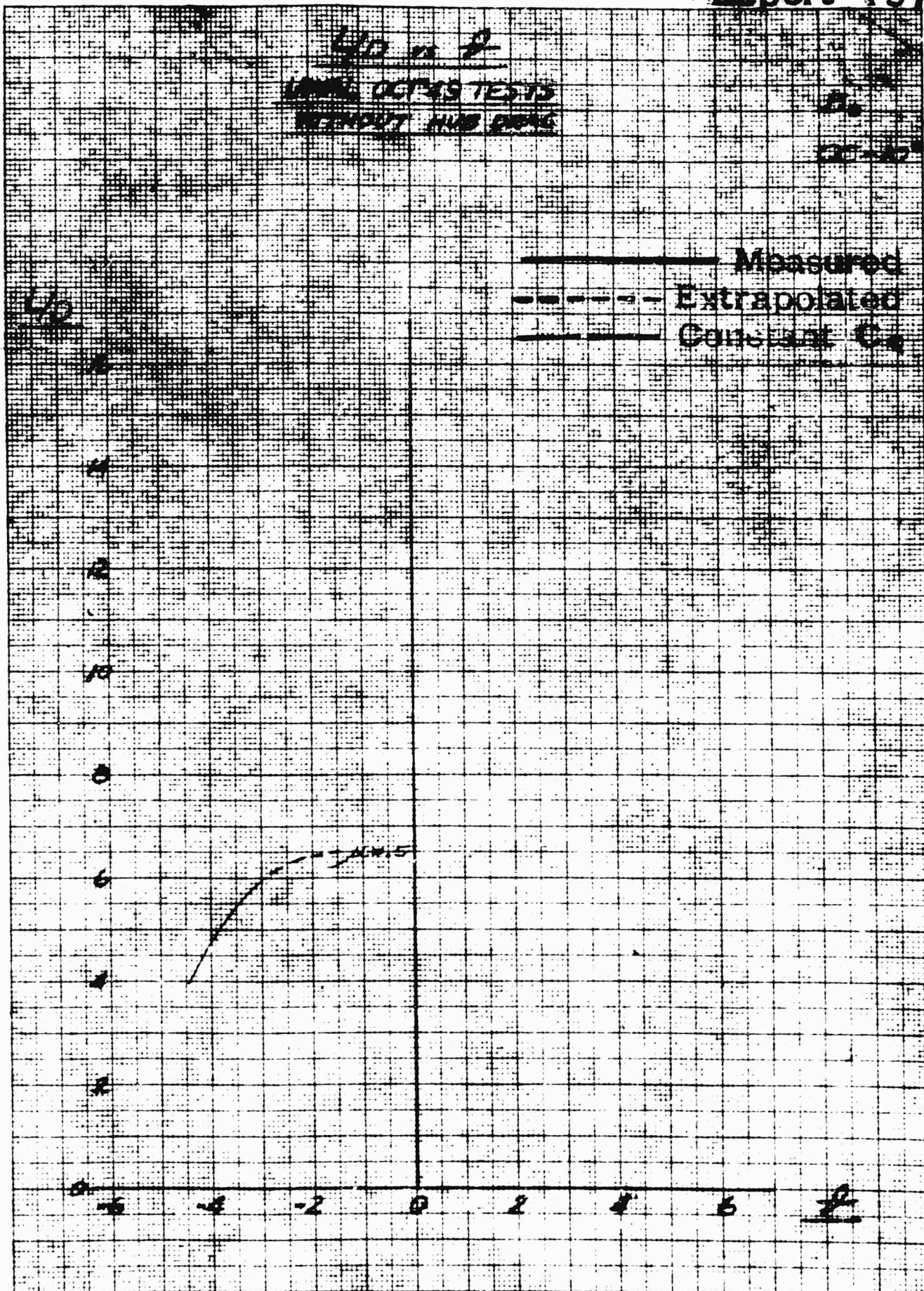
KEUFFEL & ESSER CO.

No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.

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DATE OCT 19 7 31 PM
RECEIVED FBI BUREAU

_____ Measured
 - - - - - Extrapolated
 _____ Constant C



KEUFFEL & ESSER CO.

No. 359-14. Millimeters. 5 mm lines accented cm lines heavy.

C_Q VS z

UWAL OCT 49 TESTS
WITHOUT HUB DEAD

B_0

$\alpha = 0^\circ$

$10^3 C_Q$

.4

.2

0

-.2

-.4

-.6

-.8

-1.0

-6

-4

-2

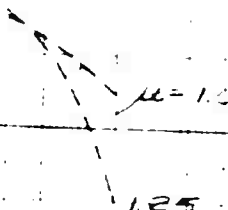
0

2

4

6

20



————— Measured
----- Extrapolated
————— Constant C

C_Q VS z

UWAL OCT 49 TESTS
WITHOUT HUB DRAG

B_0

$\alpha = 2^\circ$

$10^3 C_Q$

.4

.2

0

-.2

-.4

-.6

-.8

-1.0

-6

-4

-2

0

2

4

6

z

1.5

1.0

1.25

2.5

2.0

Measured
Extrapolated
Constant C_Q

CONFIDENTIAL

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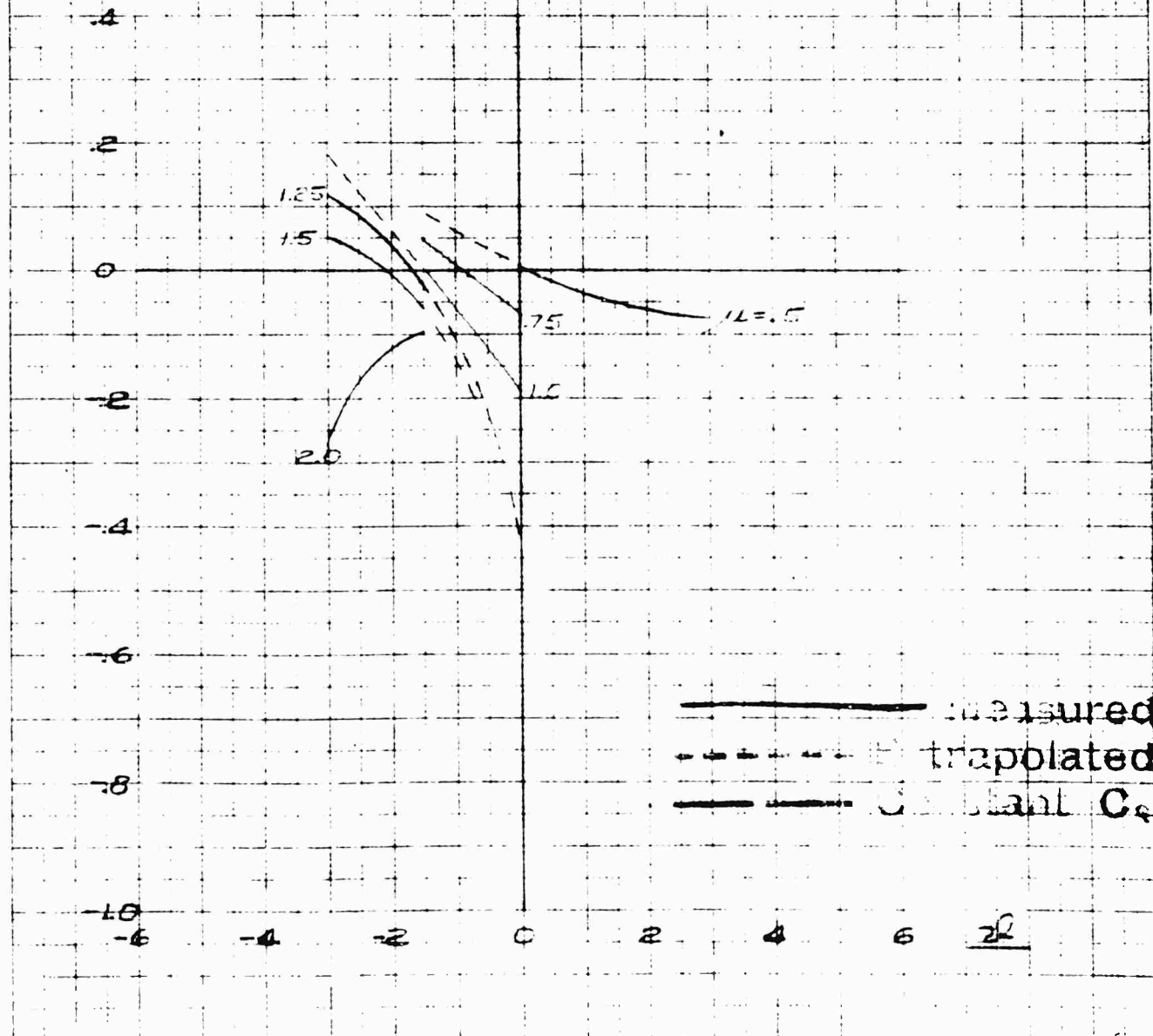
C_0 VS z

UNVAL OCT '49 TESTS
WITHOUT HUS DEAD

E_0

$\alpha = 4^\circ$

$10^3 C_0$



KELLOGG & ESCHER CO.

No 359 14 Millimeters, 5 mm lines at 1000, 200 lines heavy

C_Q VS z_0

UWAL OCT '49 TESTS
WITHOUT HUB DRAG

B_0

$\alpha = 6^\circ$

$10^3 C_Q$

.4

.2

0

-.2

-.4

-.6

-.8

-1.0

-6

-4

-2

0

2

4

6

z_0

1.25

.75

11.5

1.5

2.0

————— Measured
----- Extrapolated
————— Constant C_Q

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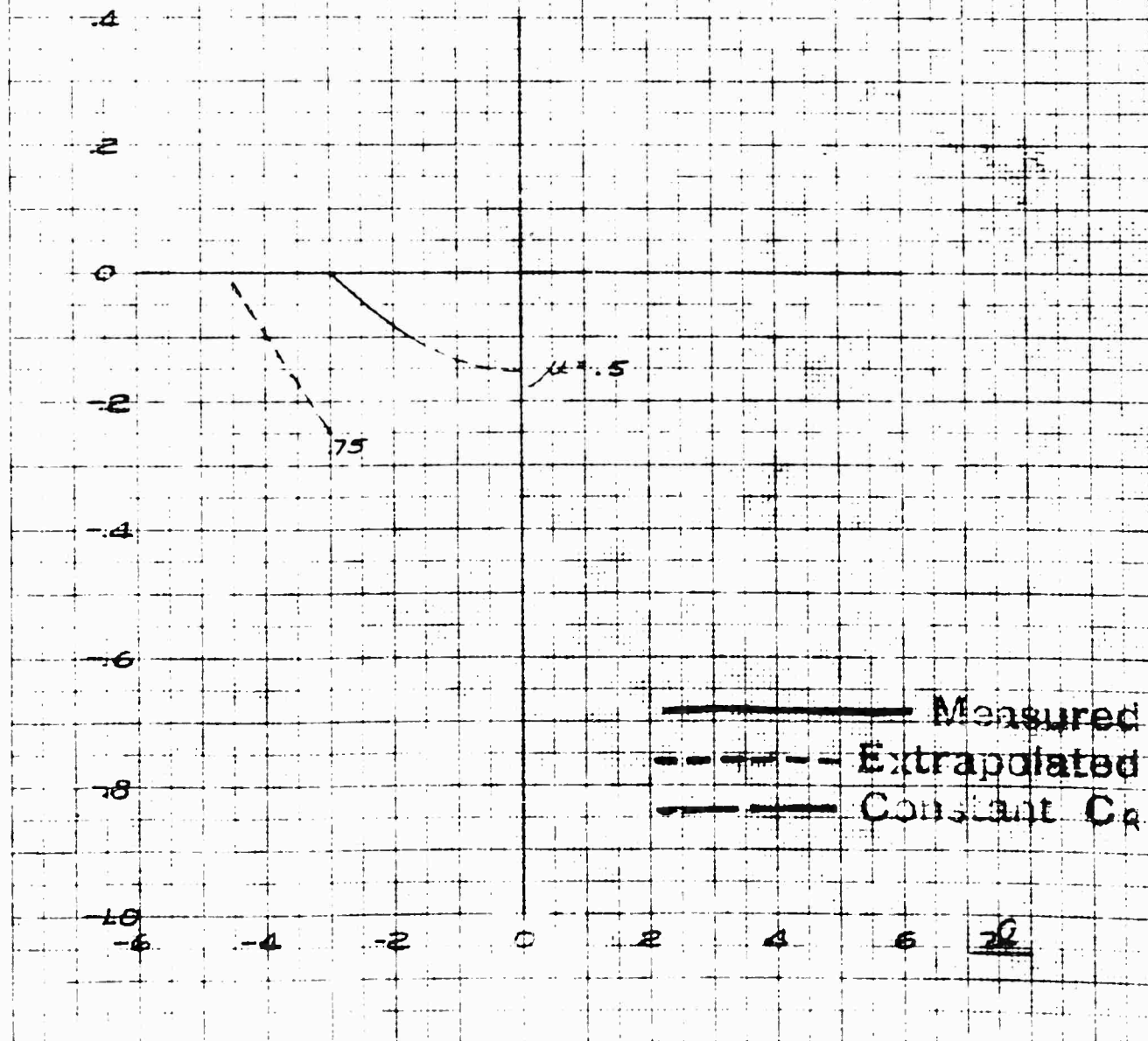
C_D VS z_D

UWAL OCT '49 TESTS
WITHOUT HUB DRAG

B.

$\alpha = 8^\circ$

$10^3 C_D$



56-1
12-44

CONFIDENTIAL

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C_0 VS T_0

UNVAL OCT 149 TESTS
WITHOUT MUD DEAS

$10^3 C_0$

4

2

0

-2

-4

-6

-8

-10

-6

-4

-2

0

2

4

6

10

$\mu = 1.5$

Measured
Extrapolated
Constant C_0

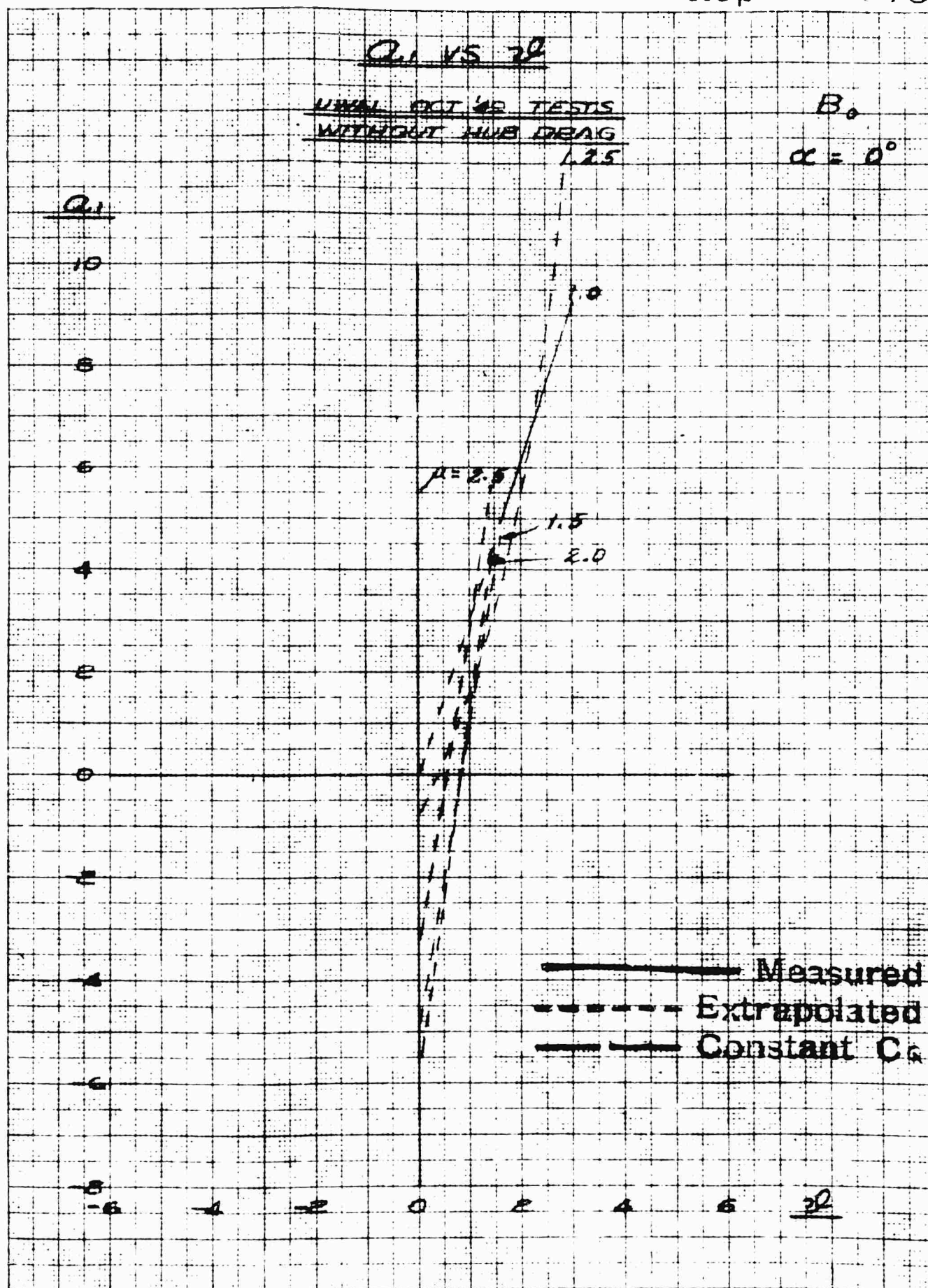
KEUFFEL & ESSER CO.

No. 359 14 Millimeter, 5 mm lines, arcuated, pen lines heavy

26-14-07

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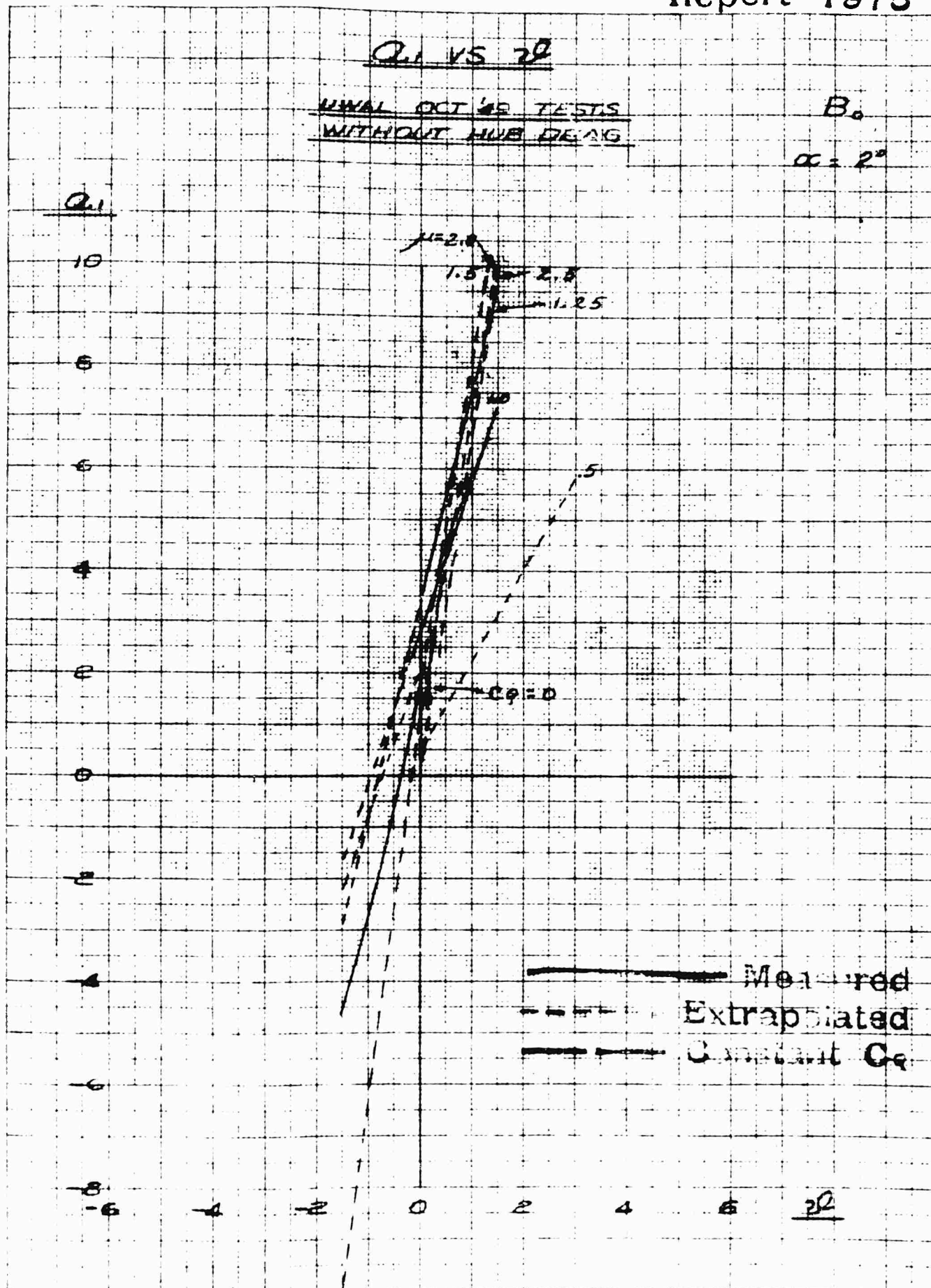


Q_L VS z

UNVAL OCT 45 TESTS
WITHOUT HUB DEAG

B_0

$\alpha = 2^\circ$



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Q₁ vs. Z

UNRAI OCT 40 TESTS
WITHOUT AND DEAG

B.

$\alpha = 4^\circ$

Q₁

10

8

6

4

2

0

-2

-4

-6

-8

-6

-4

-2

0

2

4

6

12

C010

750

600

125

$\mu = 1.5$

2.0

2.5

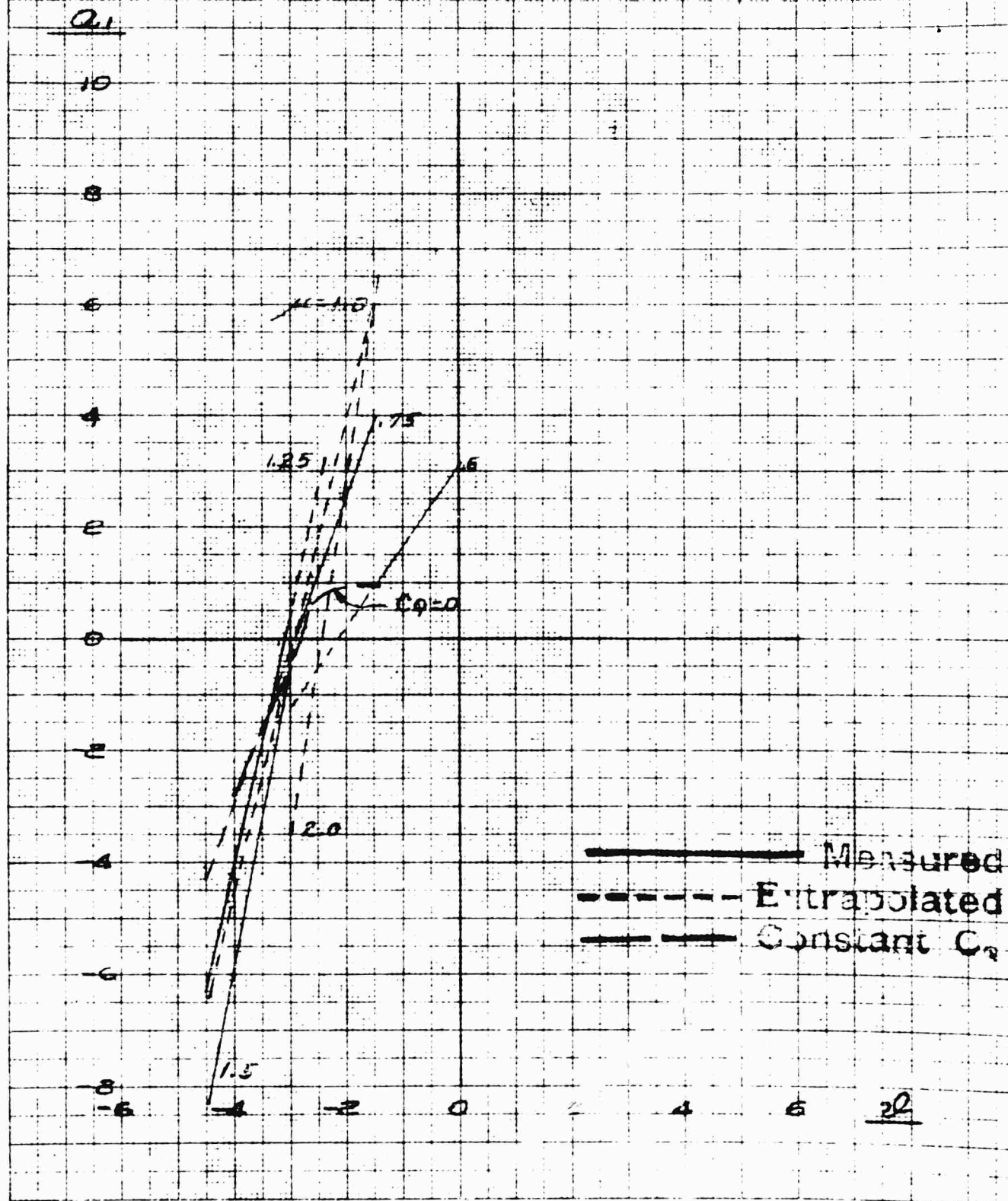
Measured
Extrapolated
Constant C_e

PB
17-940

KELFEL & ESSER CO

No 359 14 Millimeters 1/4 min lines are ruled in lines heavy

α = 6°



Q₁ VS α

UNIV. OF CALIF. TESTS
WITHOUT HUB DRAG

B₀

$\alpha = 8^\circ$

Q₁

10

8

6

4

2

0

-2

-4

-6

-8

-10

$C_q = 0$

———— Measured
----- Extrapolated
———— Constant C_q

-10

-8

-6

-4

-2

0

2

4

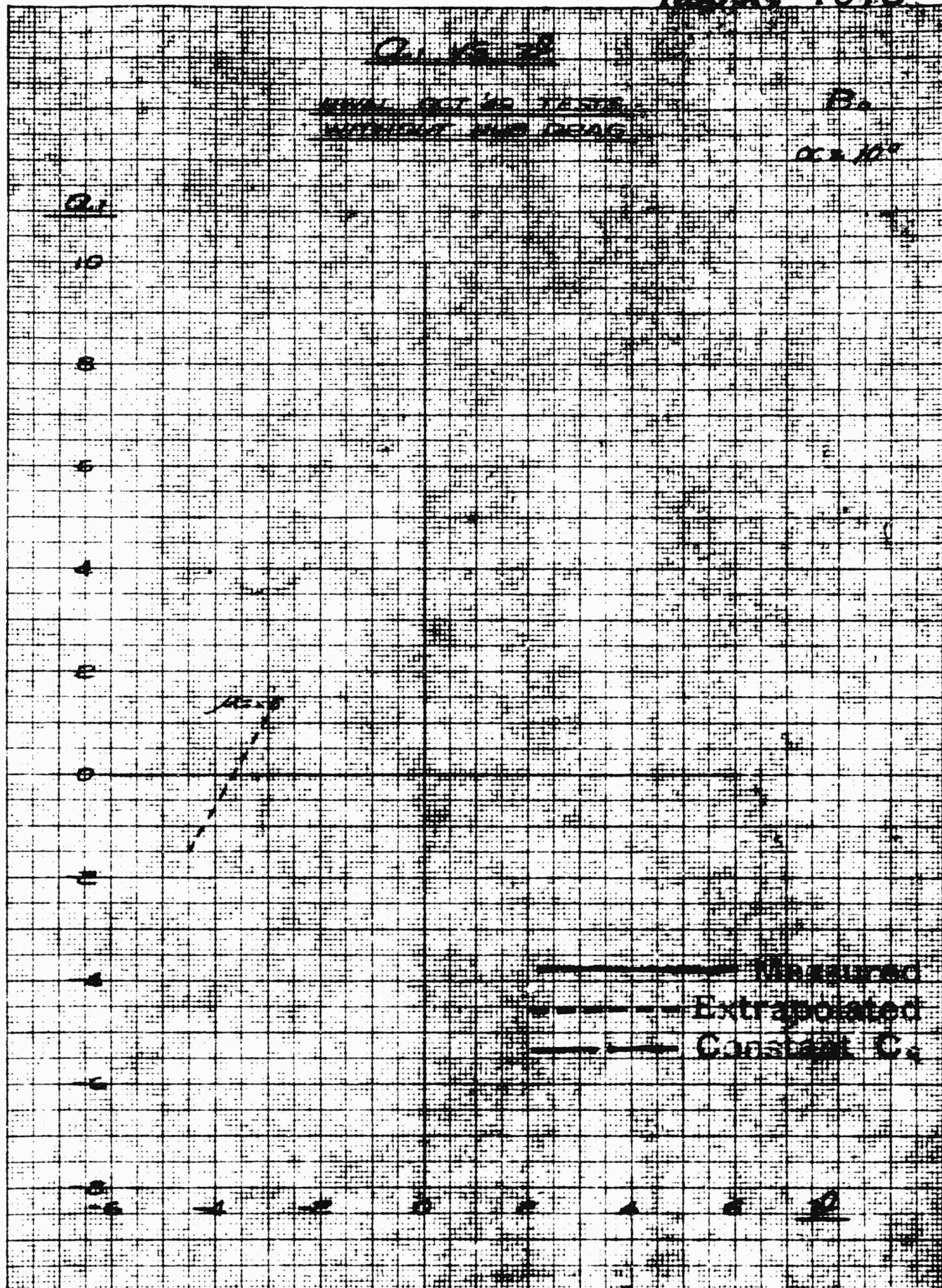
6

8

10

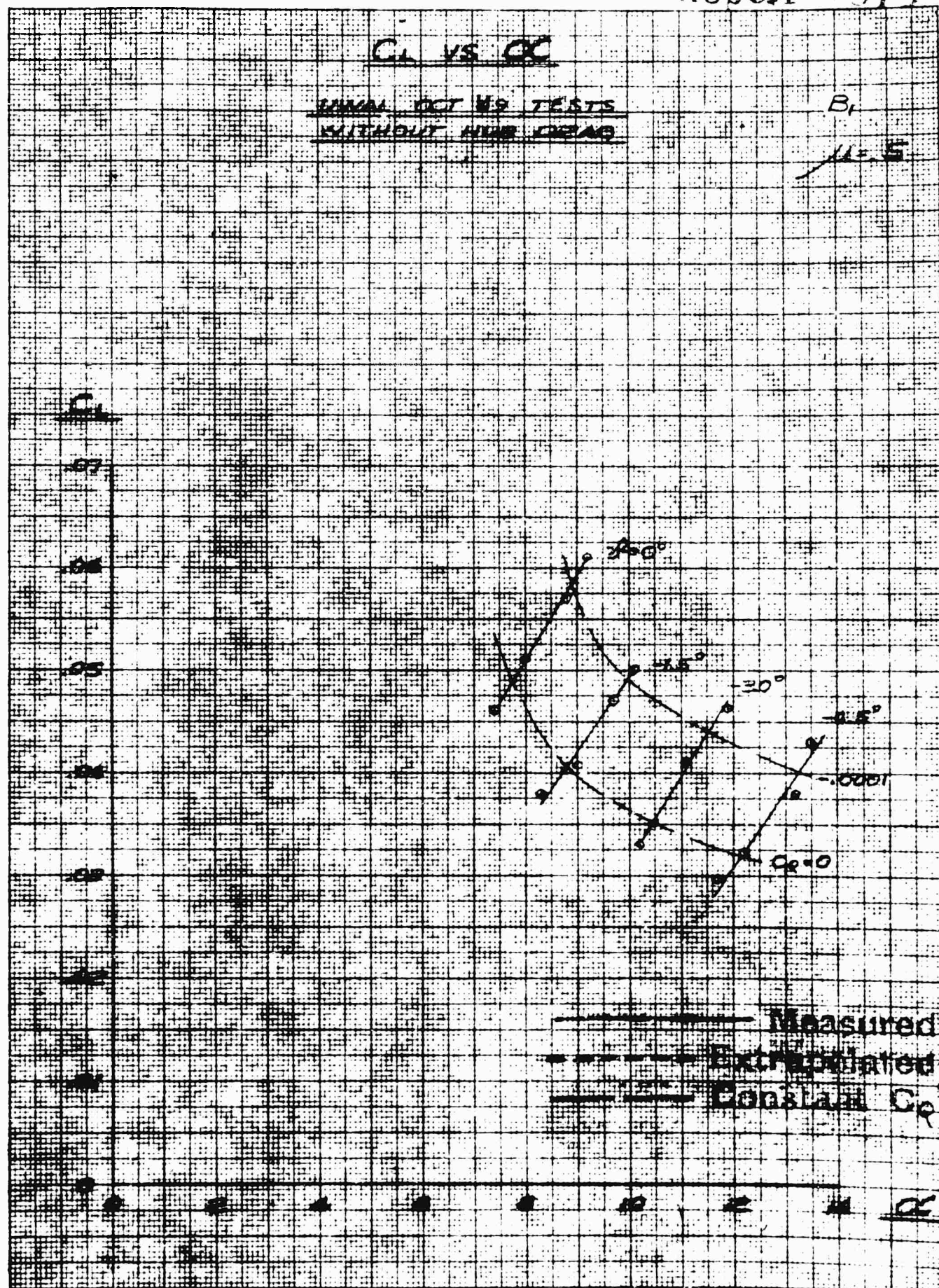
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10-5-90

CL VS CCRAWAL OCT 19 TESTS
WITHOUT HIRE DEAD B_1 $\mu = 5$ 

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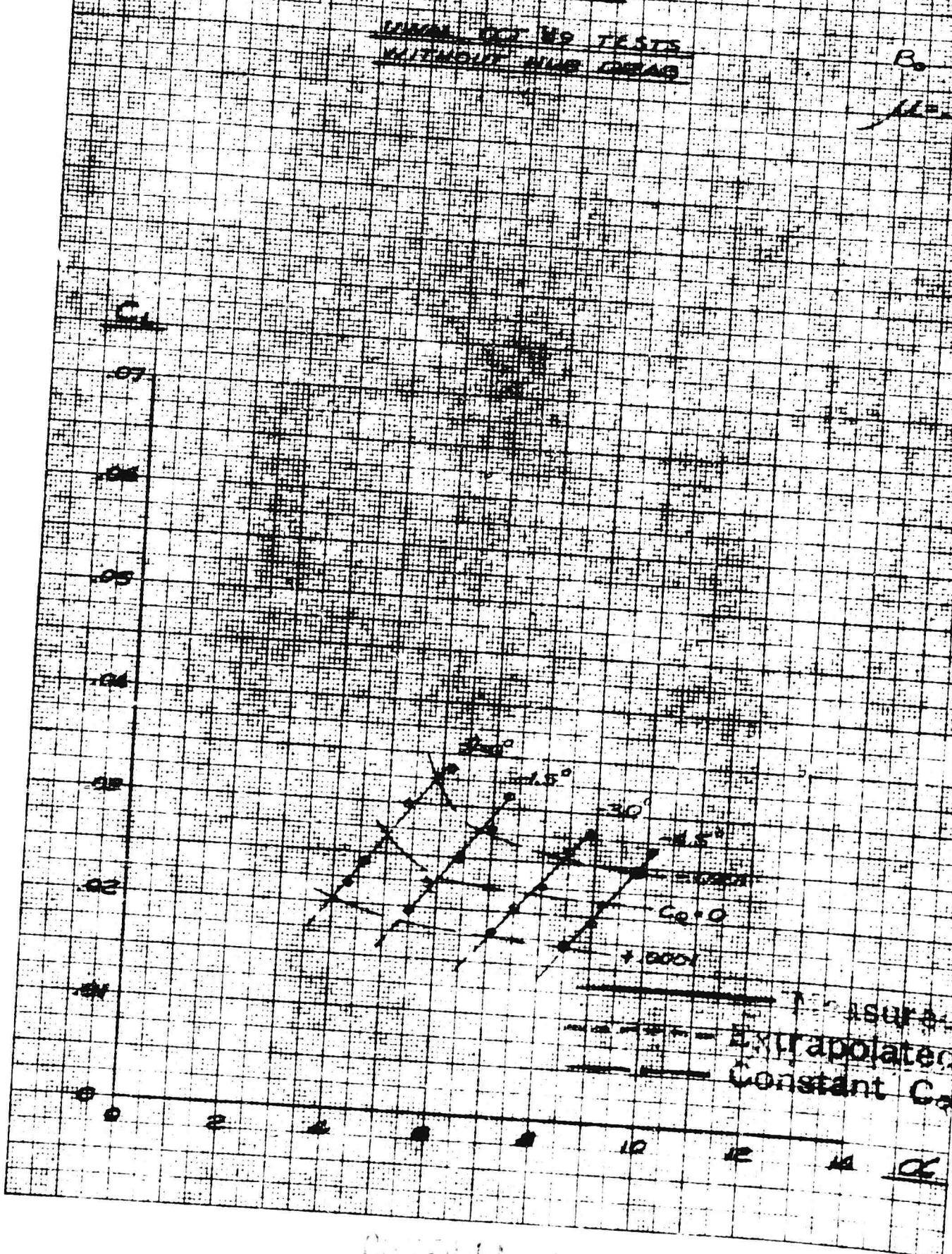
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CL VS OC

ORIGINAL OCT 89 TESTS
WITHOUT NINE DEAD

B₀

11-375

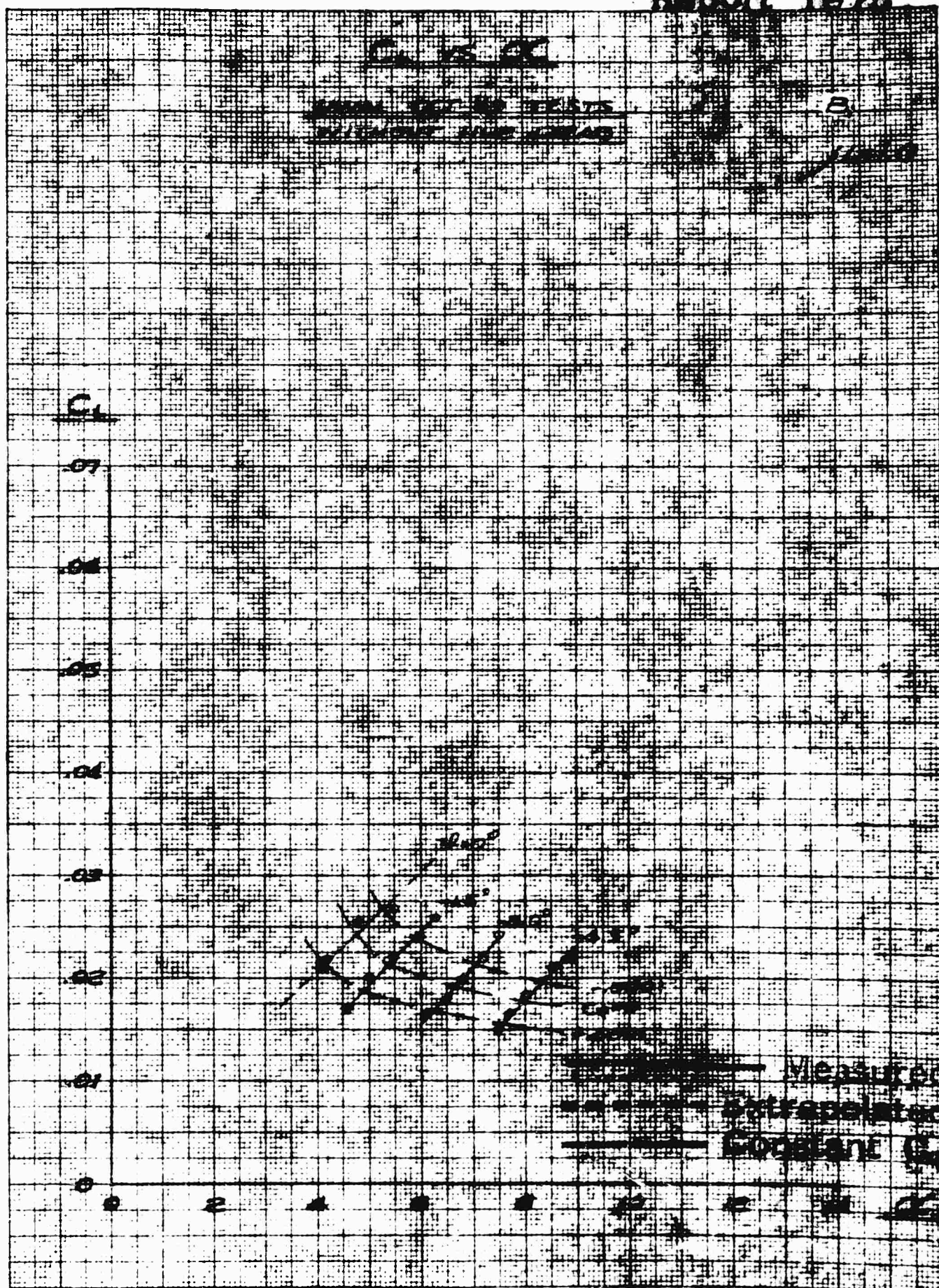


Measure
Extrapolated
Constant C₀

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CONFIDENTIAL

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KEUFFEL & ESSER CO.

No. 359 14. Millimeters, 5 mm lines accented, mm lines heavy.

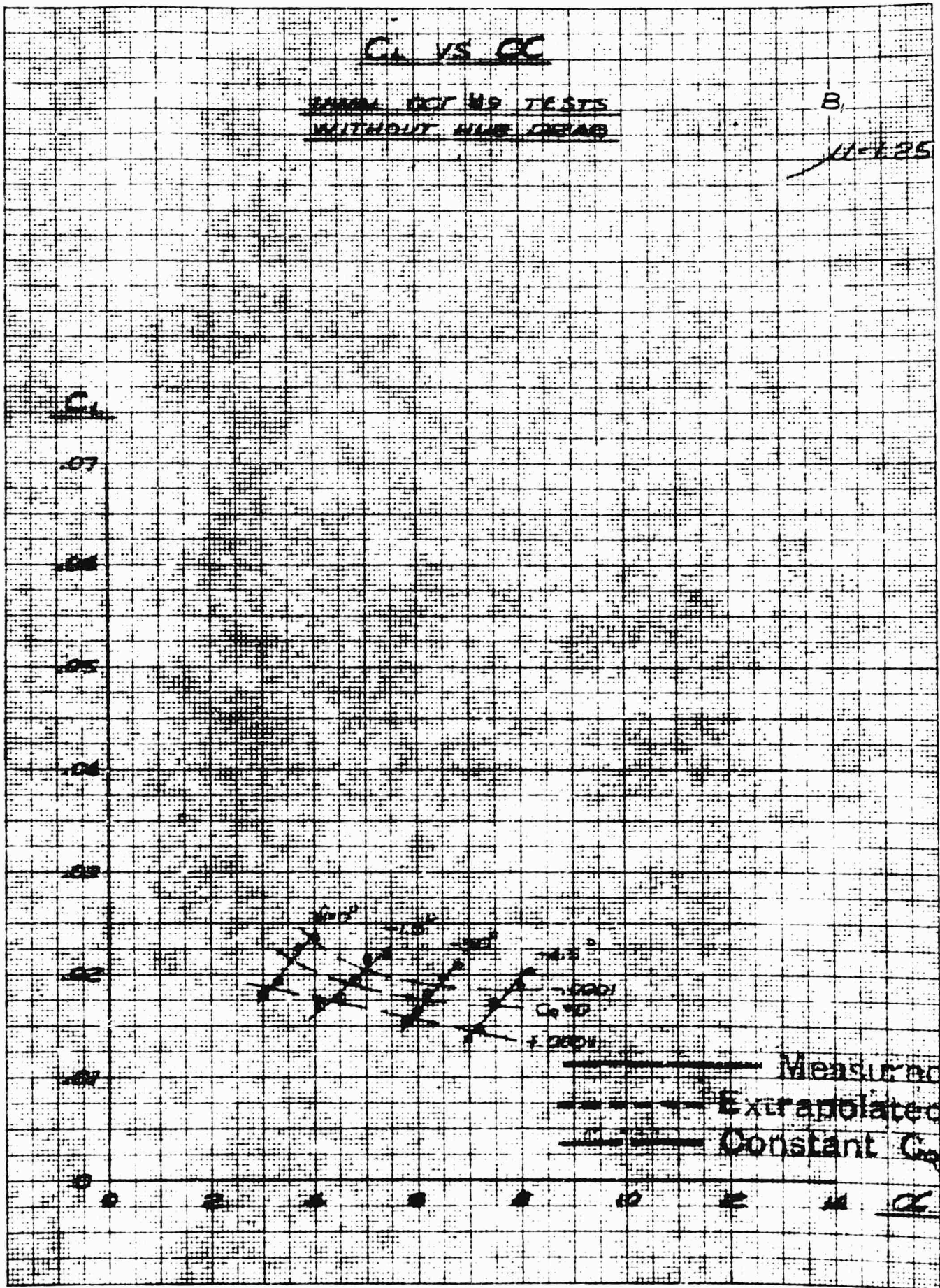
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CL VS CC

SMALL OCT 19 TESTS
WITHOUT HUB DRAG

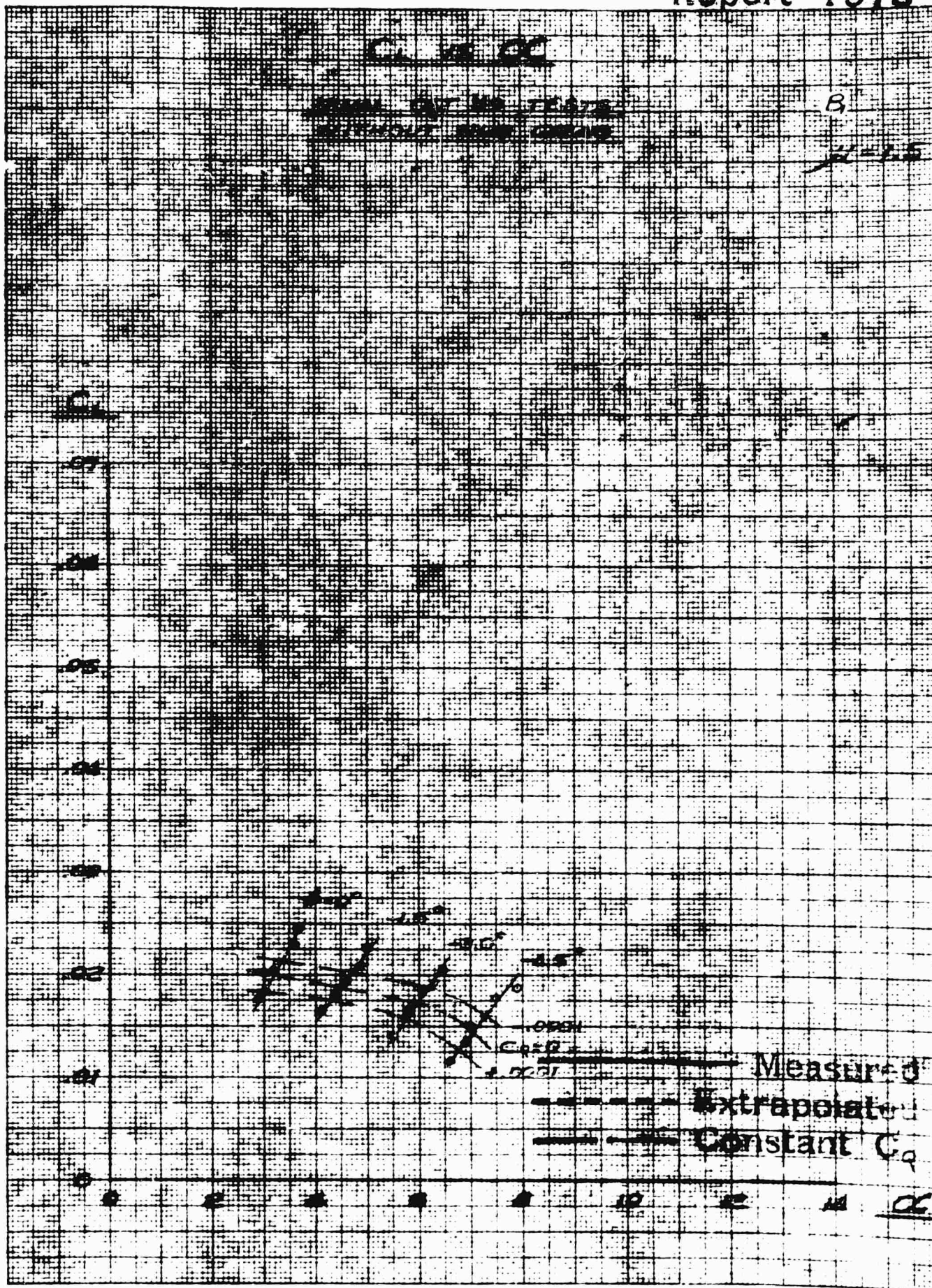
B₁

11-125



CONFIDENTIAL

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KEUFFEL & ESSER CO.

No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy

C_L VS C_C

SHOWN FOR 12 TESTS
WITHOUT HULL DAMAGE

8

C_L

0.7

0.6

0.5

0.4

0.3

0.2

0.1

0

2.0°

1.5°

1.0°

0.5°

0.0°

Measured
Extrapolated
Constant C_c

CONFIDENTIAL

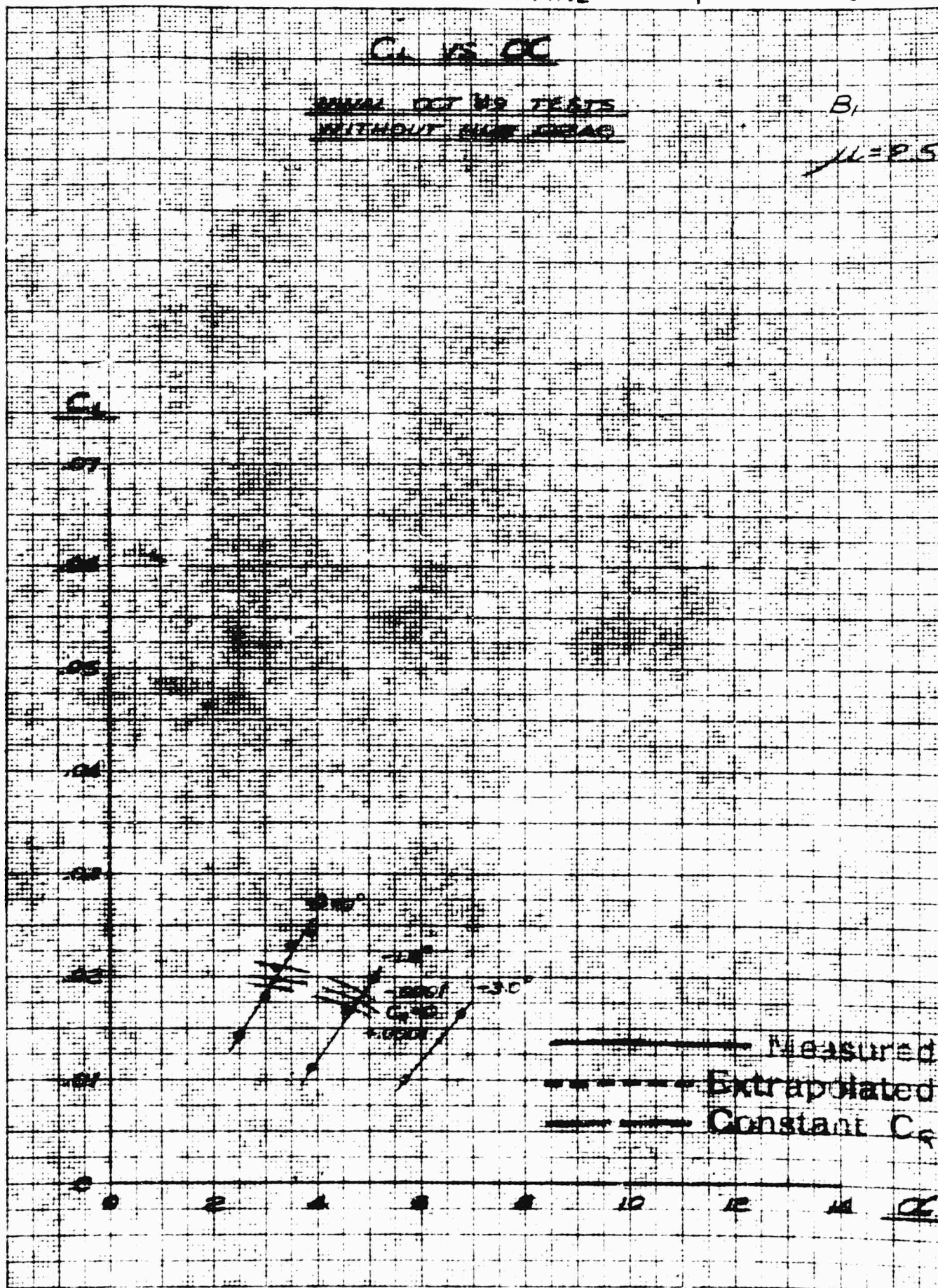
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CL VS CC

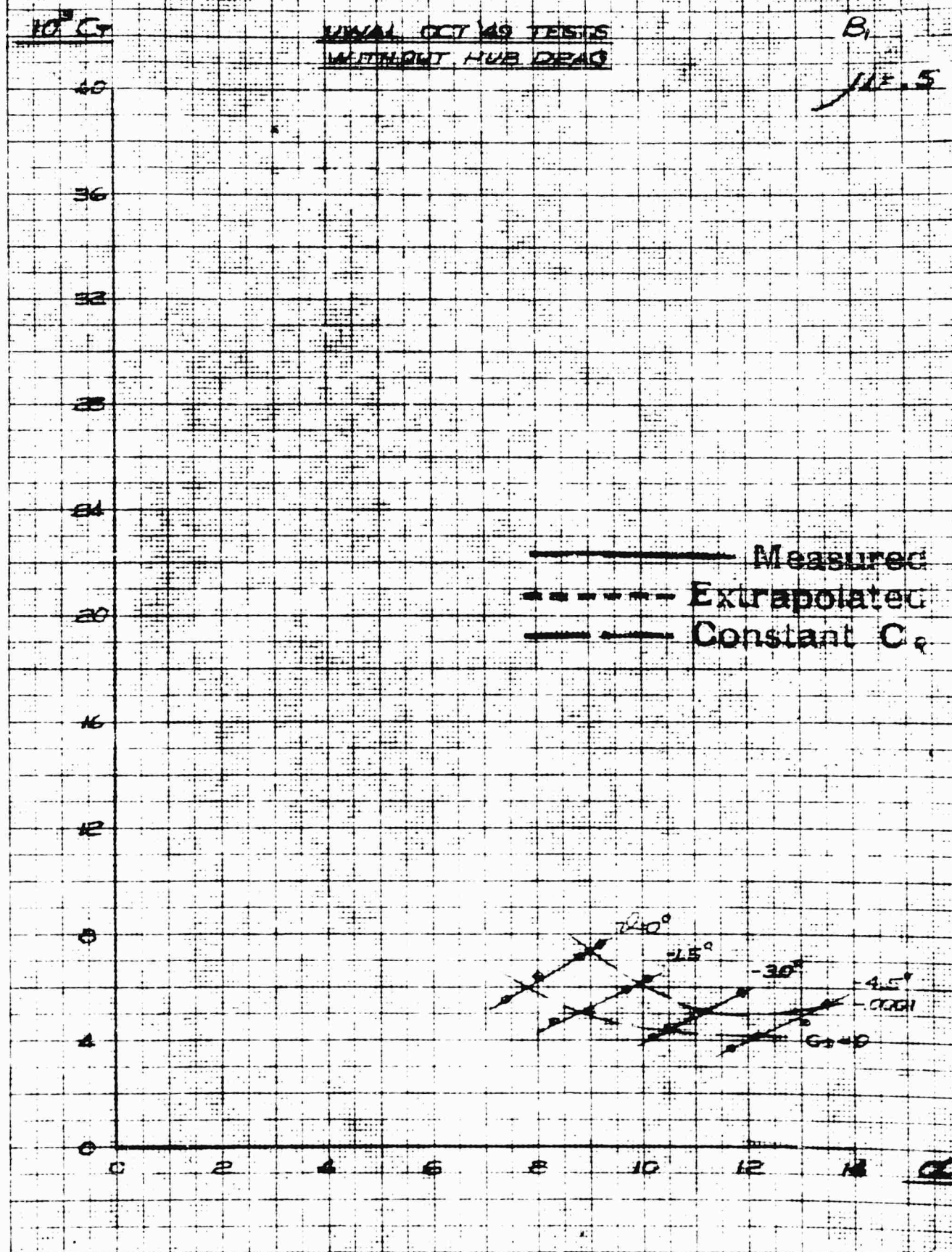
ANAL OCT 1975 TESTS
WITHOUT BUREAU DRAG

B_1

$\lambda L = 2.5$

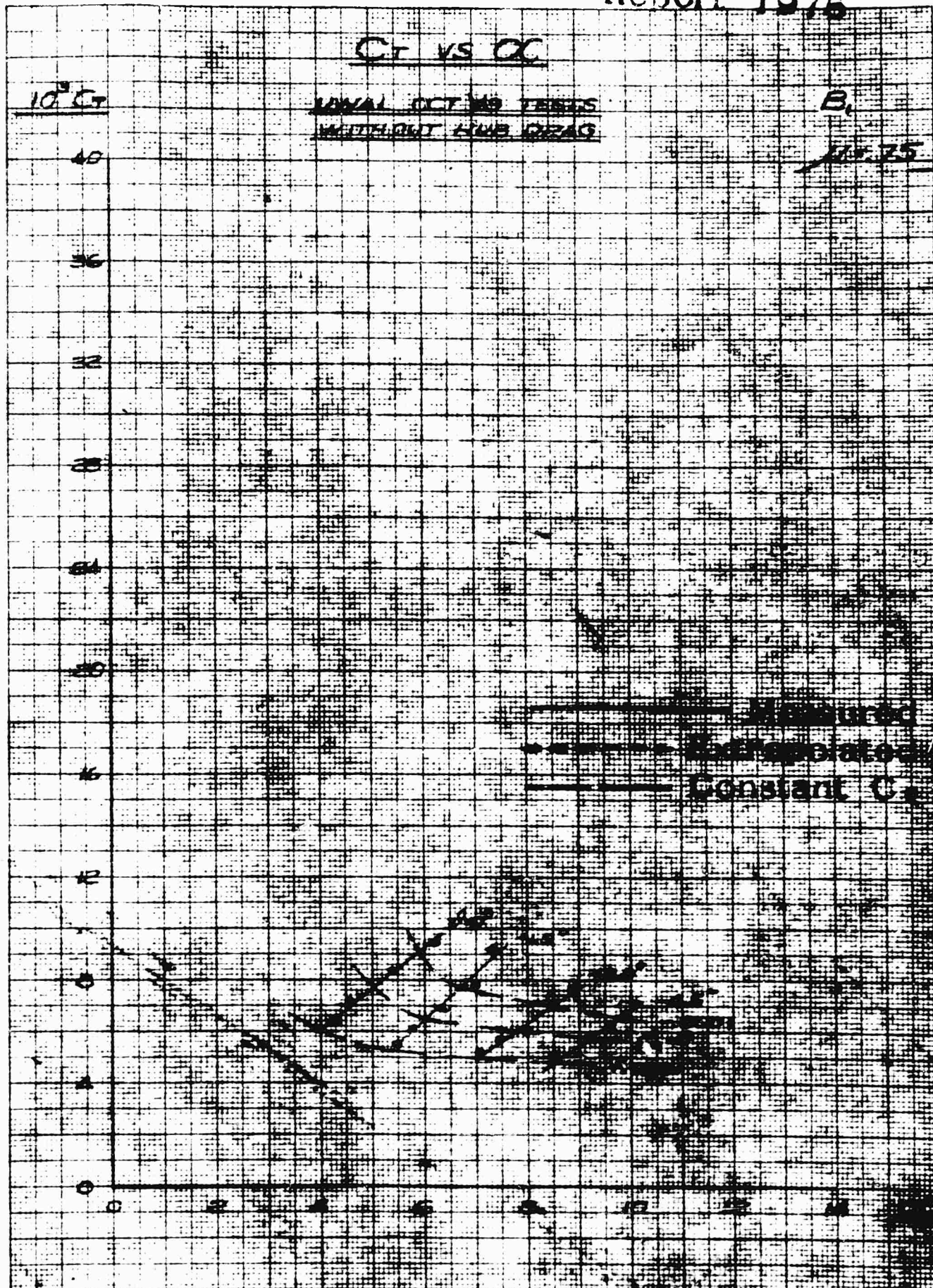


CT VS OC



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KEUFFEL & ESSER CO.

No. 359-14. Millimeters, 5 mm lines accented cm lines heavy

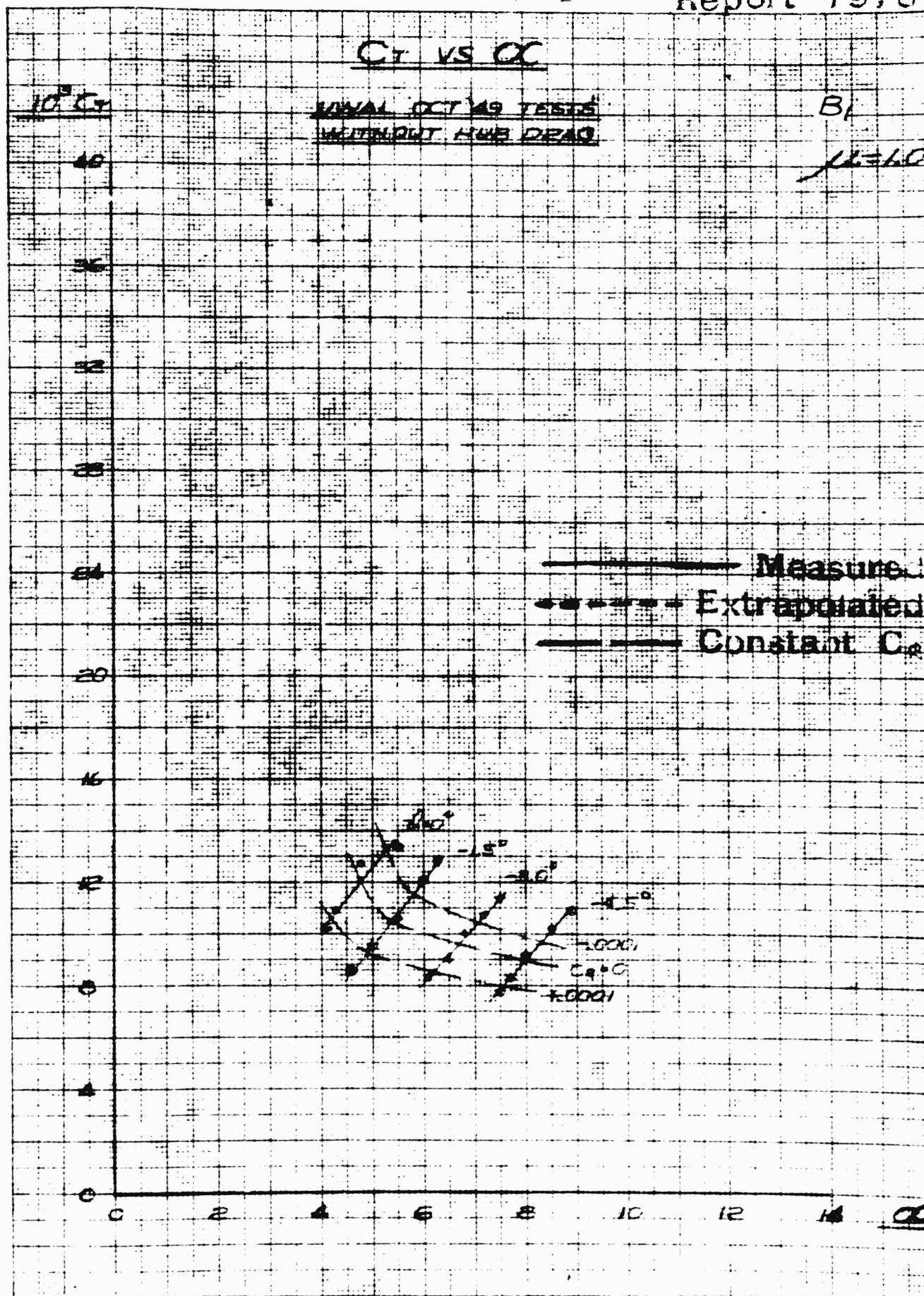
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17-02-40

CT VS QC

~~FINAL OCT 19 TESTS~~
~~MEETING HUB DEAD~~

B

 $\mu = 1.0$ 

CONFIDENTIAL

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CT VS CC

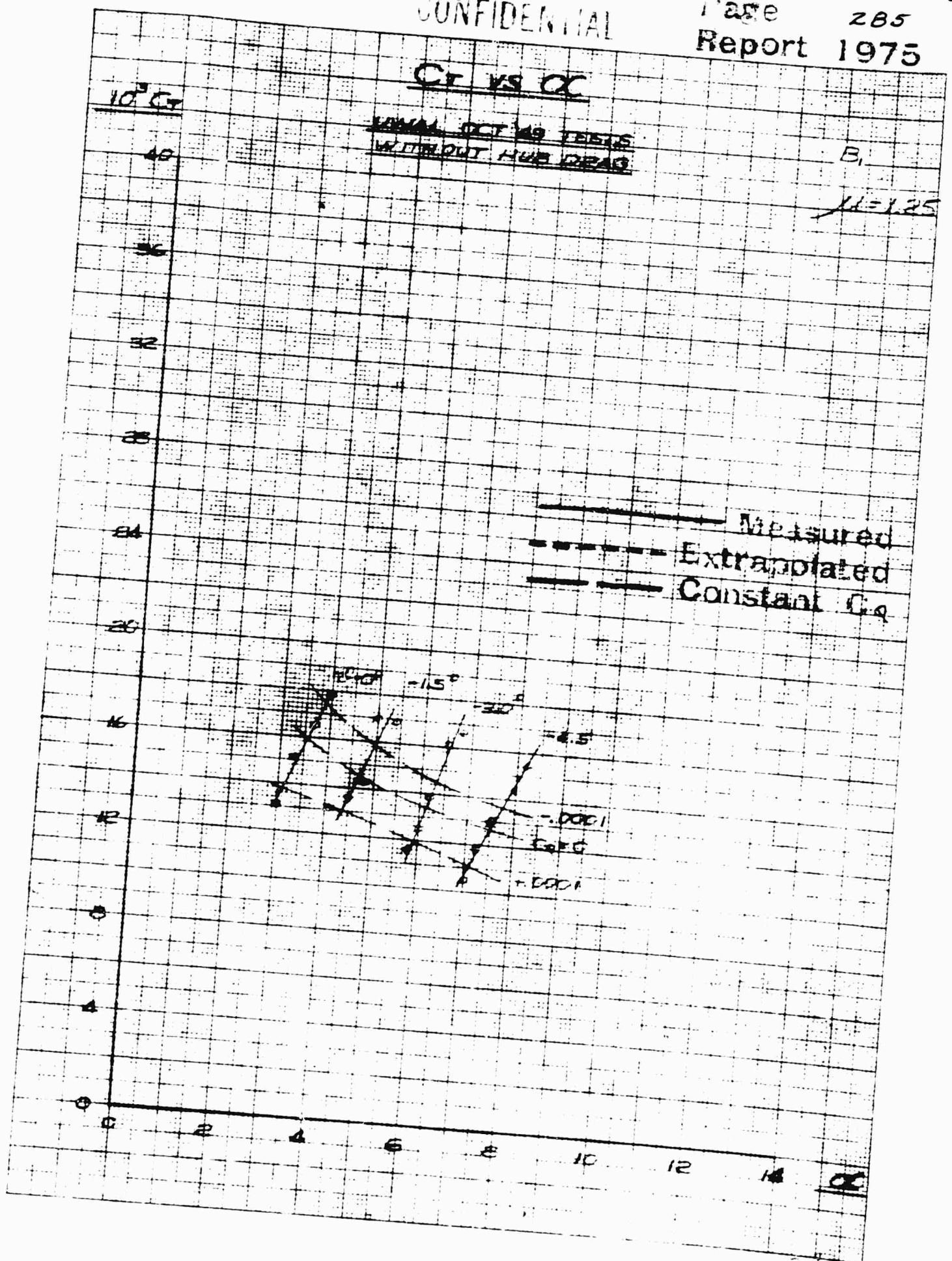
WIND TUNNEL TESTS
WITHOUT HUB DRAG

B_1

$\lambda = 1.25$

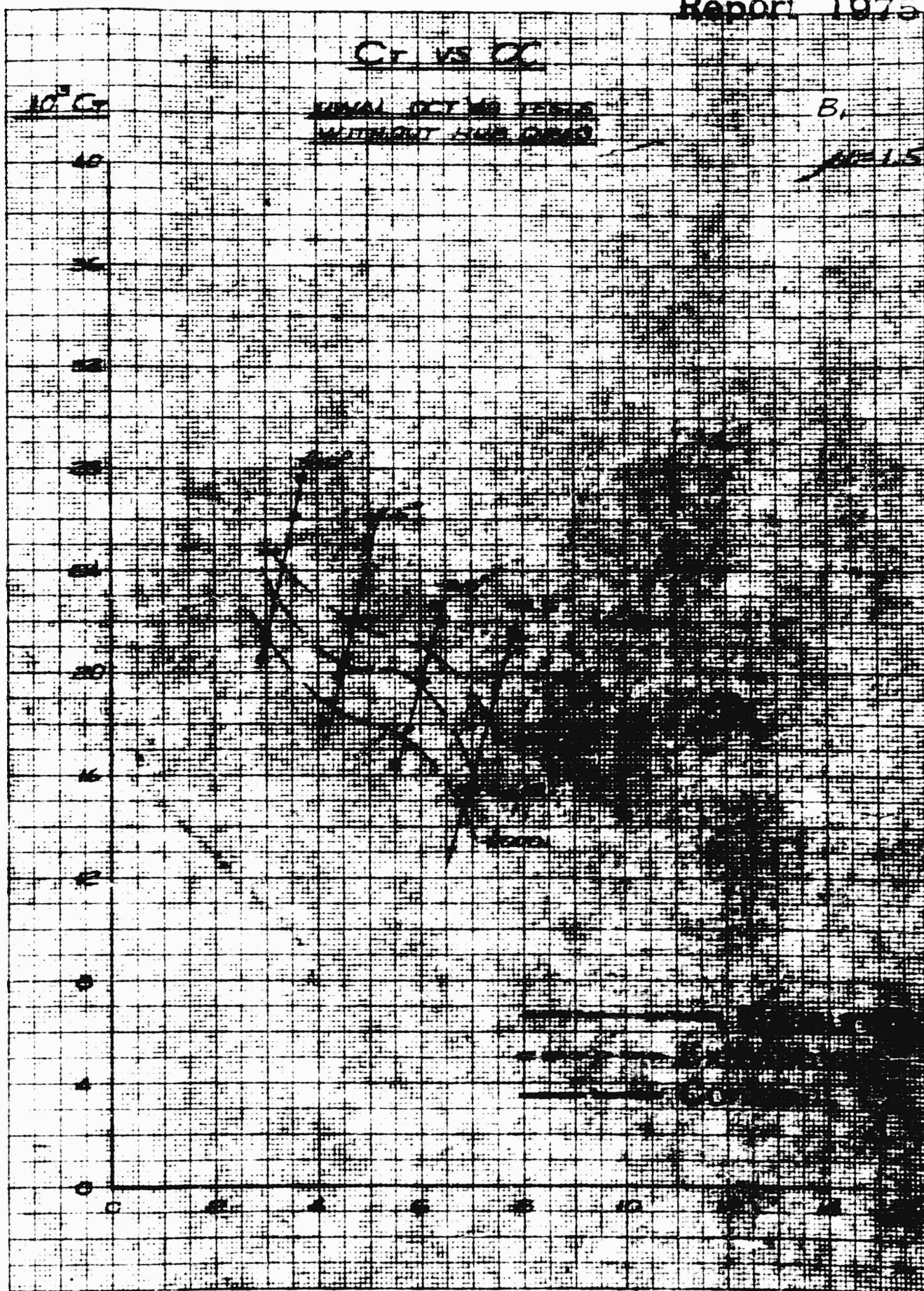
KEUFFEL & ESSER CO.

No. 392-14 Millimeter, 5 mm lines, 10 mm lines, 10 mm lines, 10 mm lines



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KEUFFEL & ESSER CO.

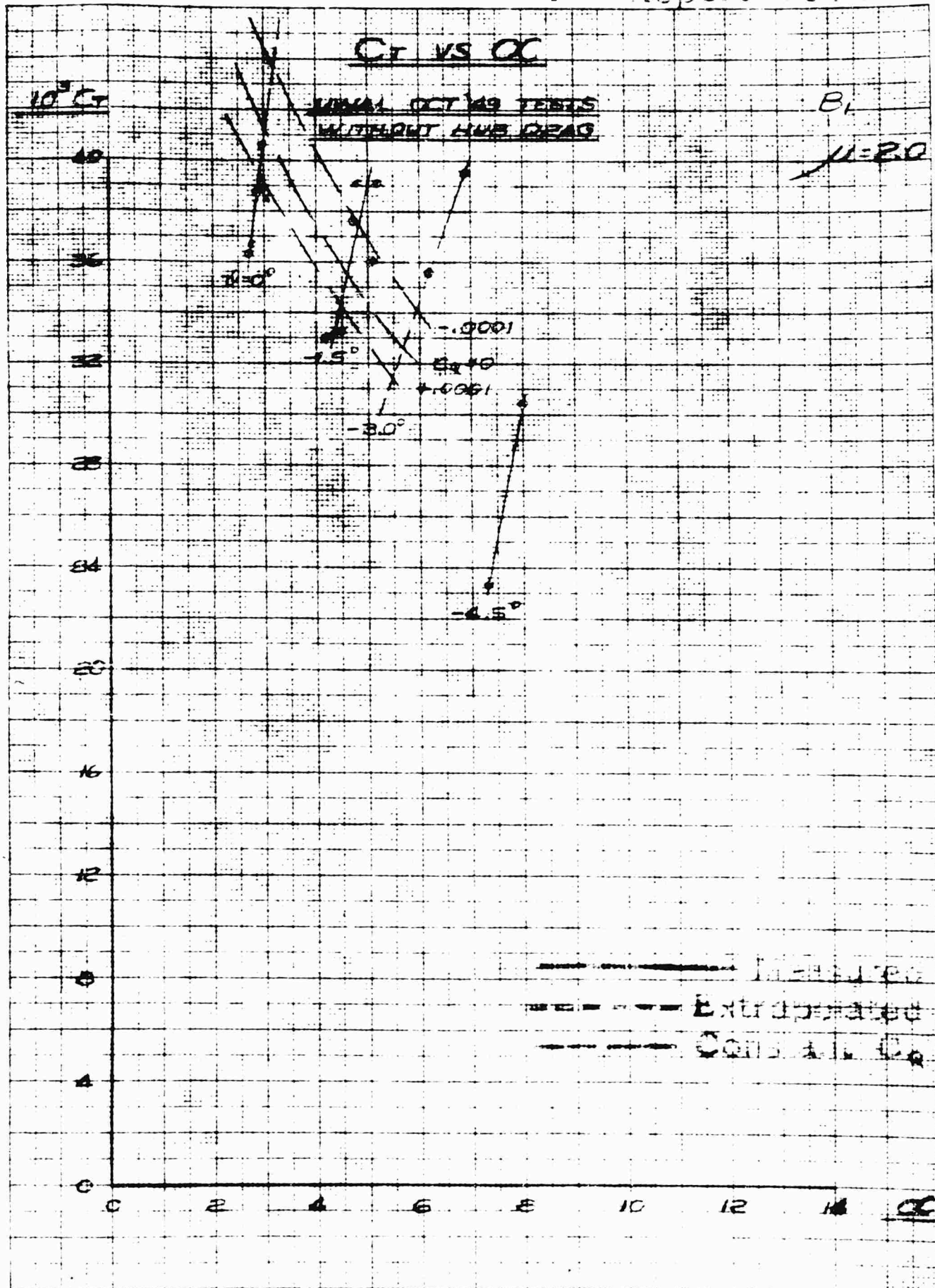
No. 359 14 Millimeter, 5 mm lines arranged, etc. lines heavy

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12-13-79

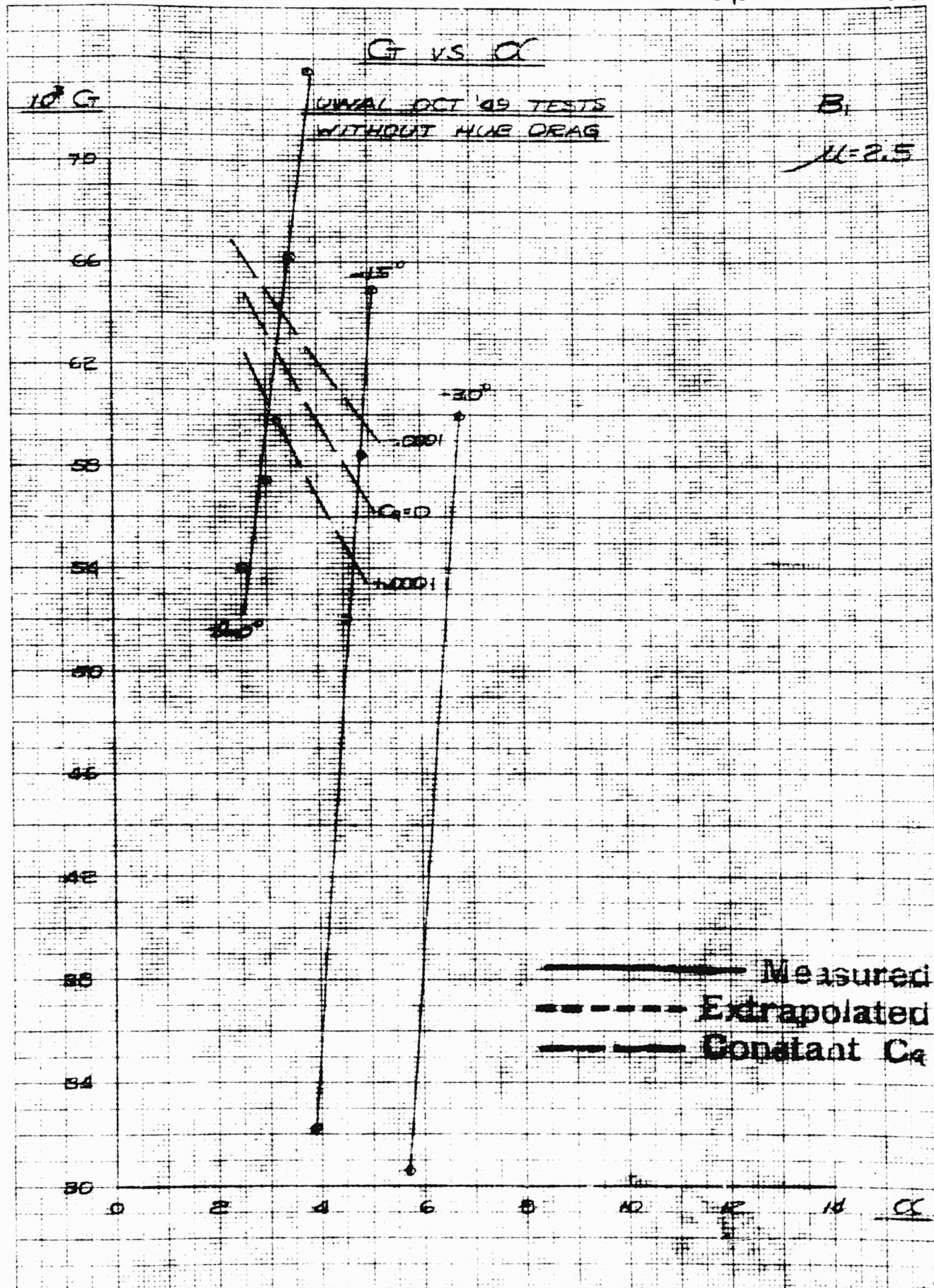
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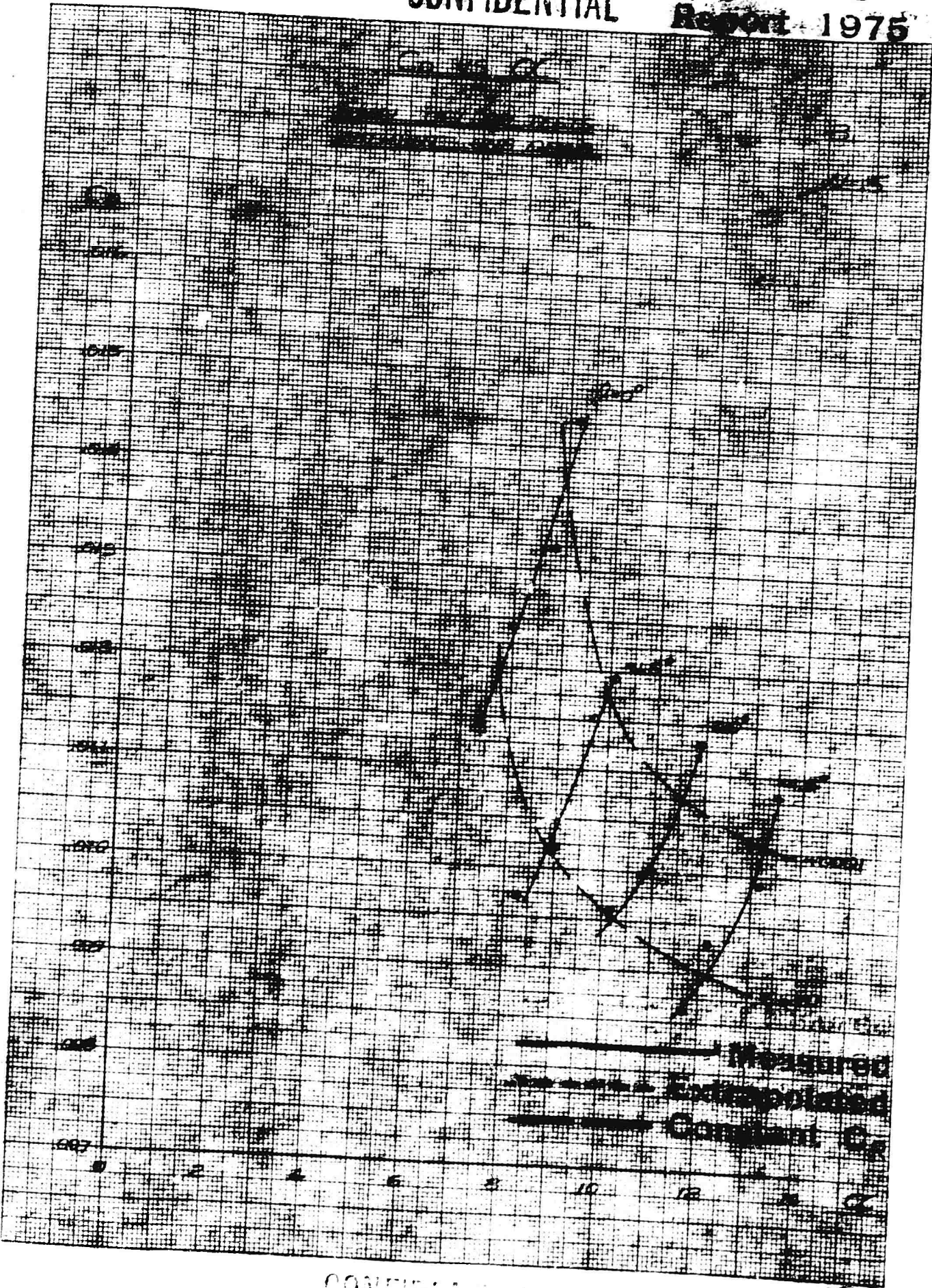


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Co. 1000

1000 1000 1000
1000 1000 1000



CONFIDENTIAL

12-14-75

NO. 300-1A
WINDMILLER 2 mm lines recorded on lines paper

KENTILL & LIPPER CO.

Co vs C_g

SEVERAL PGT AND TESTS
WITHOUT AND WITH

E_p

11-75

C_g

0.010

0.009

0.008

0.007

0.006

0.005

0.004

0.003

0.002

0.001

0

2

4

6

8

10

12

14

16

18

20

Measured
Extrapolated
Corrected C_g

C_D vs Re

WIND TUNNEL TESTS
WITHOUT FLOW CURVES

$N=10$

C_D

.010

.008

.007

.006

.005

.004

.003

.002

.001

0

2

4

6

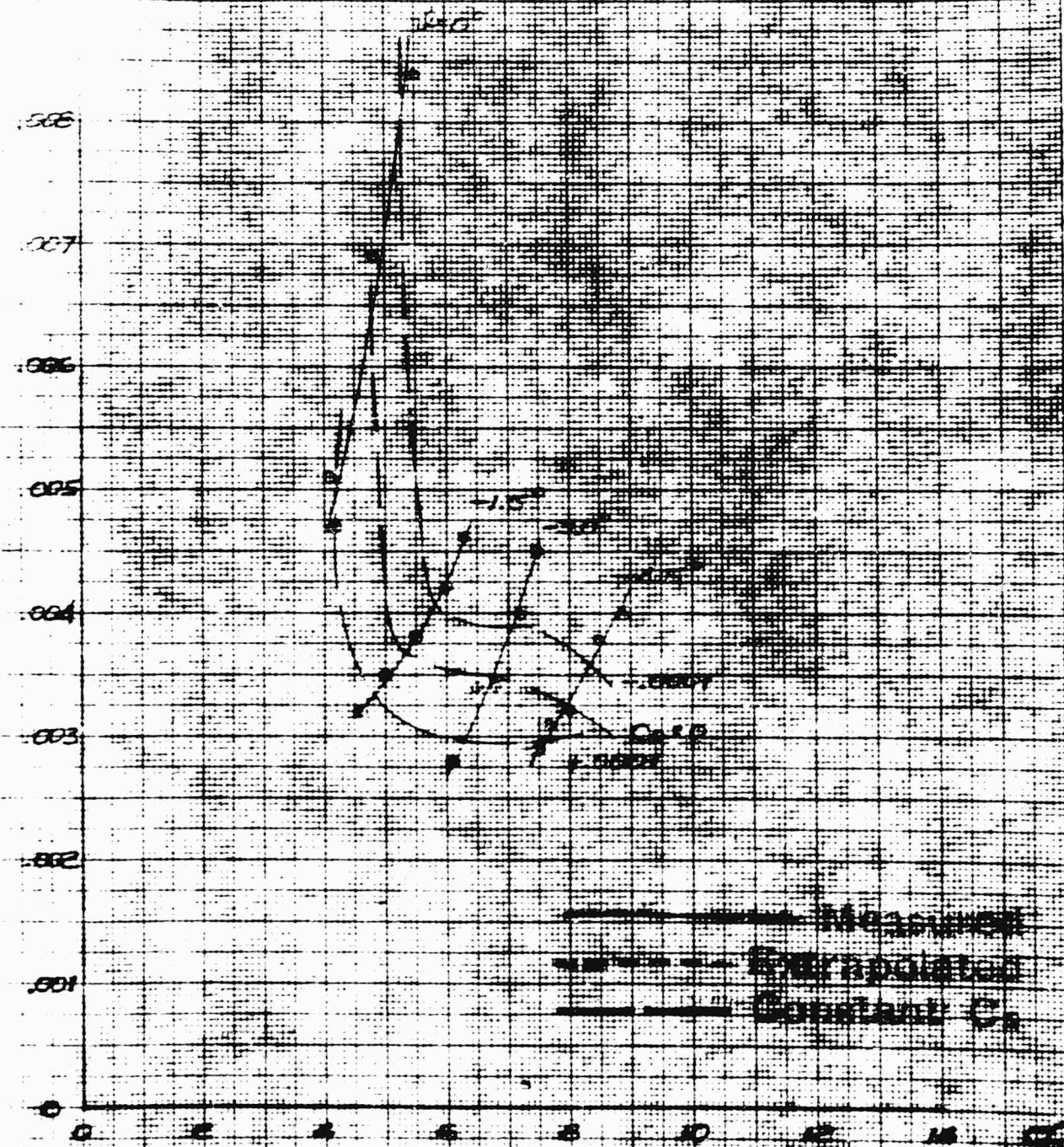
8

10

12

14

16



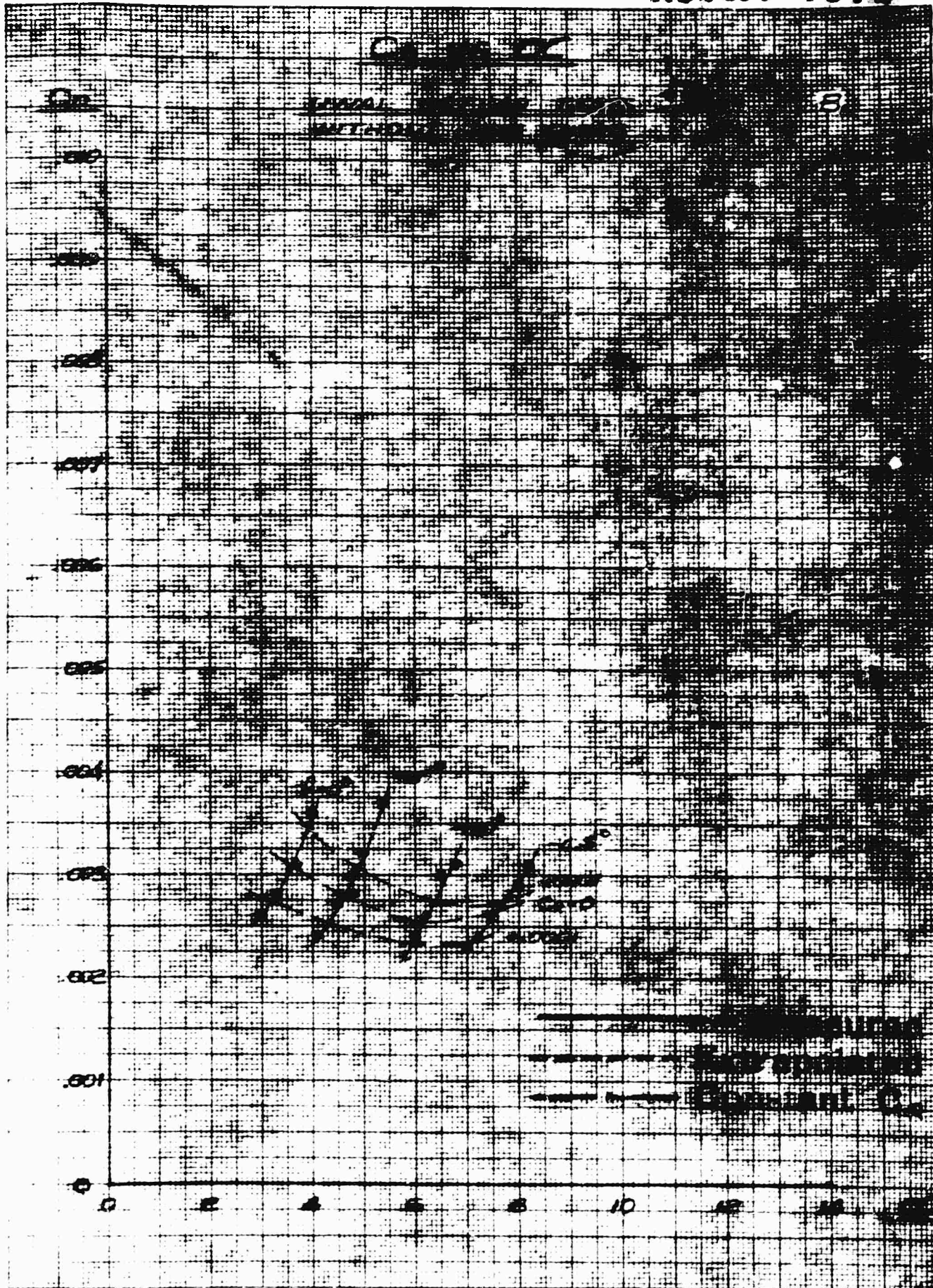
Measured
 Extrapolated
 Constant C_D

KLUPPEL & ESSER CO

No 35914. Millimeter, 5 mm lines accented on lines heavy

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12 13-40

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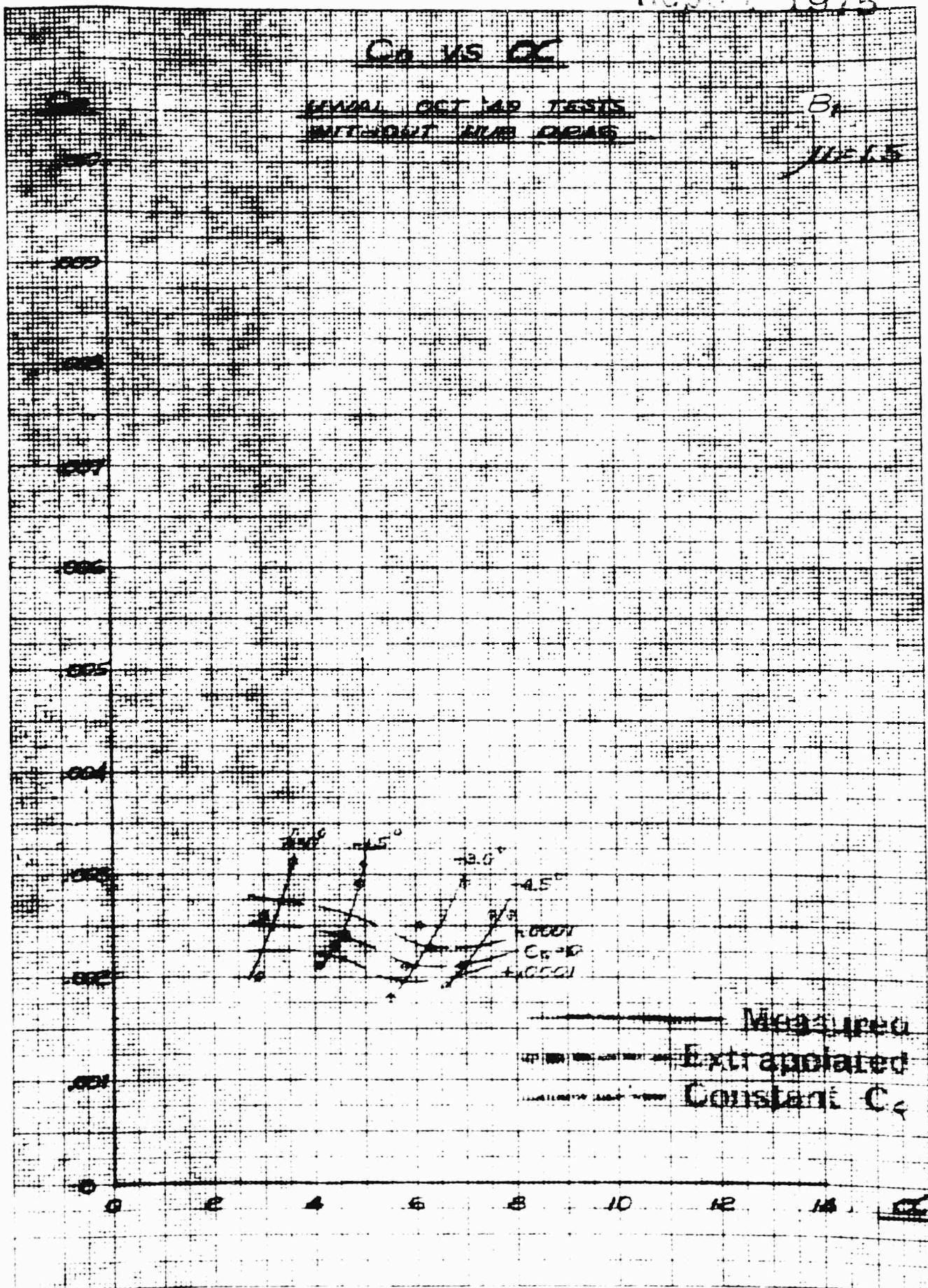
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Co vs OC

SEVERAL OCT 140 TESTS
WITHOUT HUB DEAR

B₁

11.5

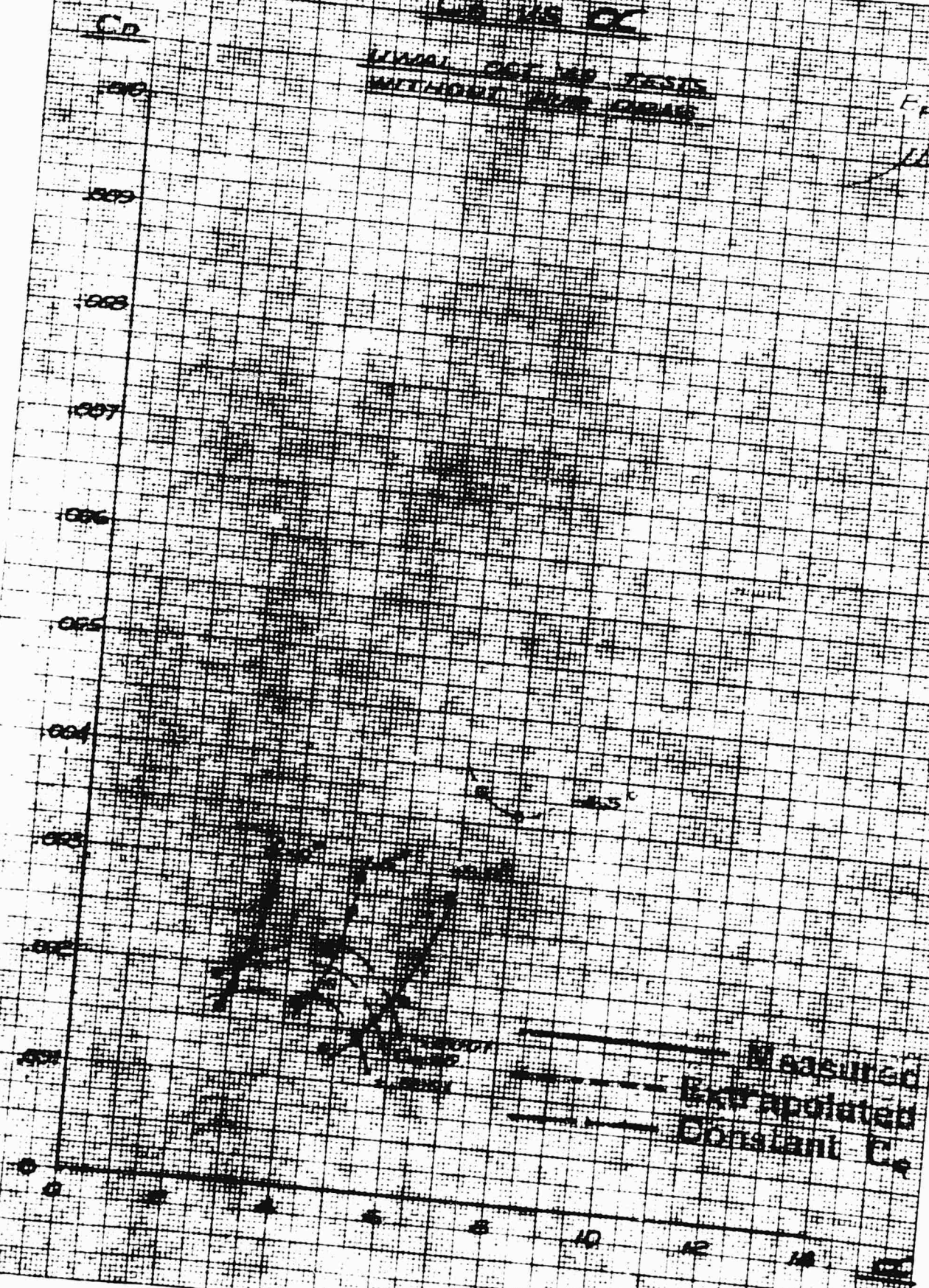


CD VS CX

UNUAL OCT 50 TESTS
WITHOUT AIR DRAG

E_r

$U=210$

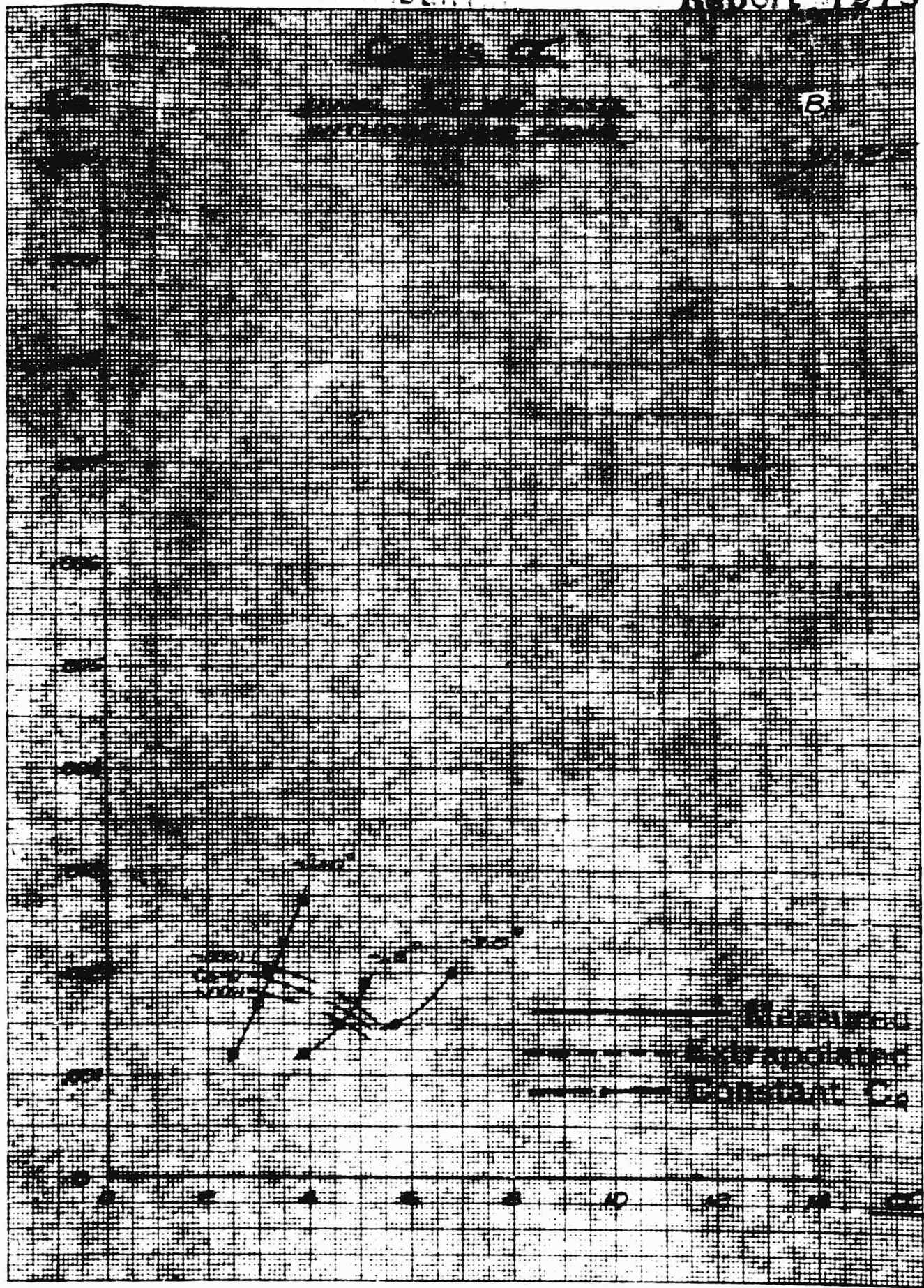


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KEUFEL & ESSER CO.

No. 1-9-14 Millimeters, 5 mm lines centered, cm lines heavy



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L/D vs OC

UNVAL OCT 19 TESTS
WITHOUT HUB DRAG

B₁

H = .5

L/D

16

14

12

10

8

6

4

2

0

0

2

4

6

8

10

12

14

OC

— Measured
- - - Extrapolated
— Constant C_d



L/D VS OC

UNVAL OCTAG TESTS
WITHOUT HUE DRAG

C₁

AL=75

L/D

16

14

12

10

8

6

4

2

0

———— Measured
 - - - - - Extrapolated
 ——— Constant C_q

C_q=0

-7.5°

-2.5°

-4.5°

C_q=0

0

2

4

6

8

10

12

14

OC

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L/D VS OC

UNIAL OCTAG TESTS
WITHOUT HUB DRAG

B₁

11.70

L/D

16

14

12

10

8

6

4

2

0

0

2

4

6

8

10

12

14

16

Measured
Extrapolated
Constant C₁



12-18-65

L/D vs OC

UNWAL OCT 49 TESTS
WITHOUT HUE, DRAG

R₁

U#125

L/D

16

14

12

10

8

6

4

2

0

0

2

4

6

8

10

12

14

OC

drag

30°

45°

60°

————— Measured
- - - - - Extrapolated
————— Constant C_q

L/D vs OC

UNVAL OCTAG TESTS
WITHOUT HUE DRAG

B_L

REF. 5

L/D

16

14

12

10

8

6

4

2

0

0

2

4

6

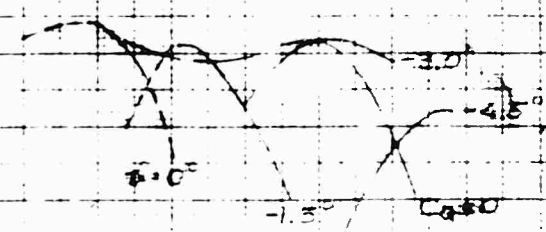
8

10

12

14

OC



----- Measured
- - - - - Extrapolated
----- Constant L₀

L/D vs. OC

UNVAL OCT 49 TESTS
WITHOUT HUB DRAG

E.

N=20

L/D

16

14

12

10

8

6

4

2

0

0

2

4

6

8

10

12

14

16

Measured
Extrapolated
Constant C_d

12/12/49

L/D VS OC

WIND TUNNEL TESTS
WITHOUT HUB DRAG

B.

$\mu = 2.5$

L/D

16

14

12

10

8

6

4

2

0

C_{p0}

1.75°

3.0°

————— Measured
- - - - - Extrapolated
- - - - - Constant C_e

0

2

4

6

8

10

12

14

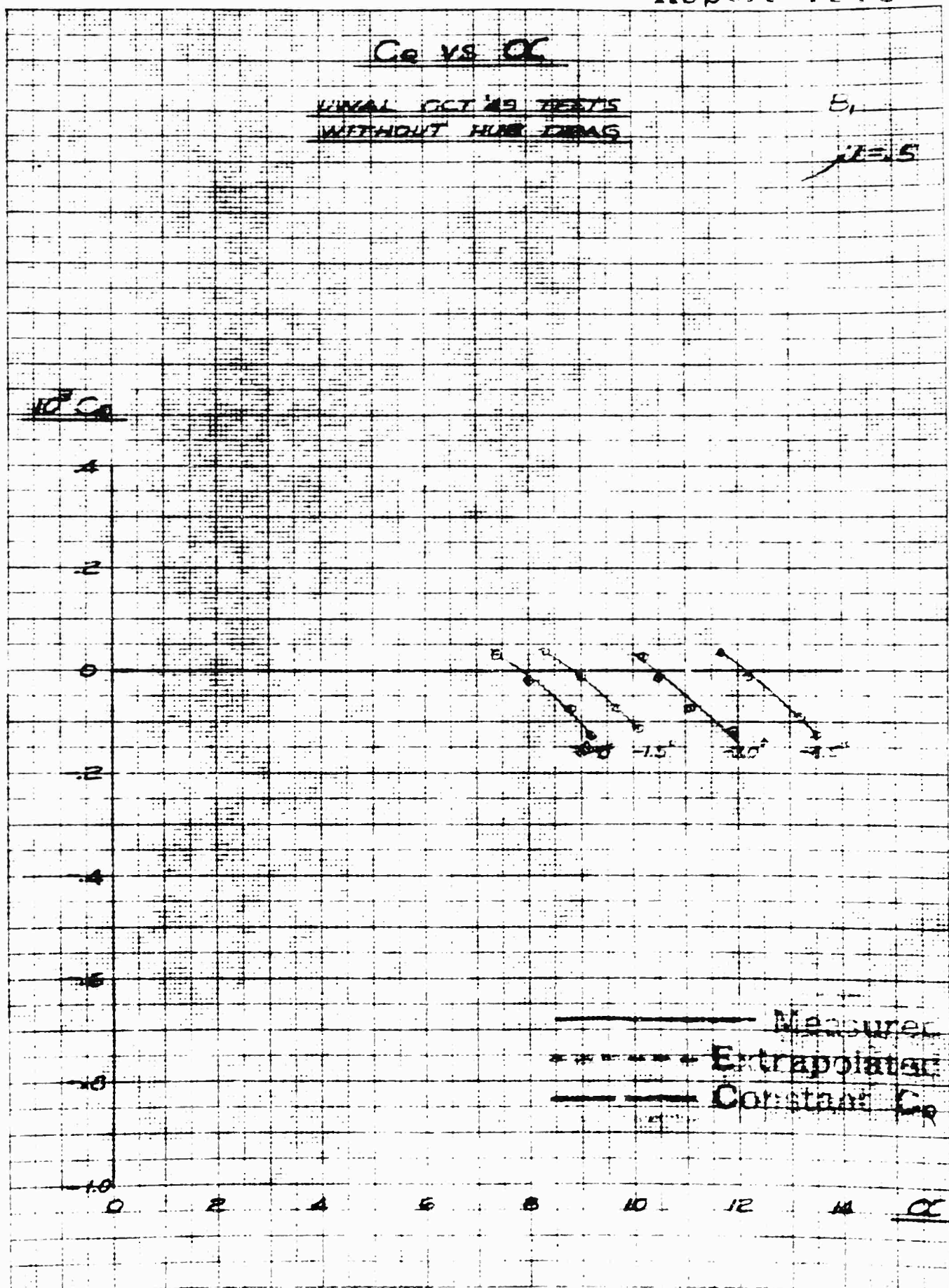
OC

Ce vs OC

UNVAL OCT 49 TESTS
WITHOUT HUB DRAG

B₁

NE-5



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C_d vs α

FINAL OCT 19 TESTS
WITHOUT HULL DRAG

E.

$U = 10$

$10^3 C_d$

4

2

0

-2

-4

-6

-8

-10

0

2

4

6

8

10

12

14

α

-1.5°

-3.2°

-4.5°

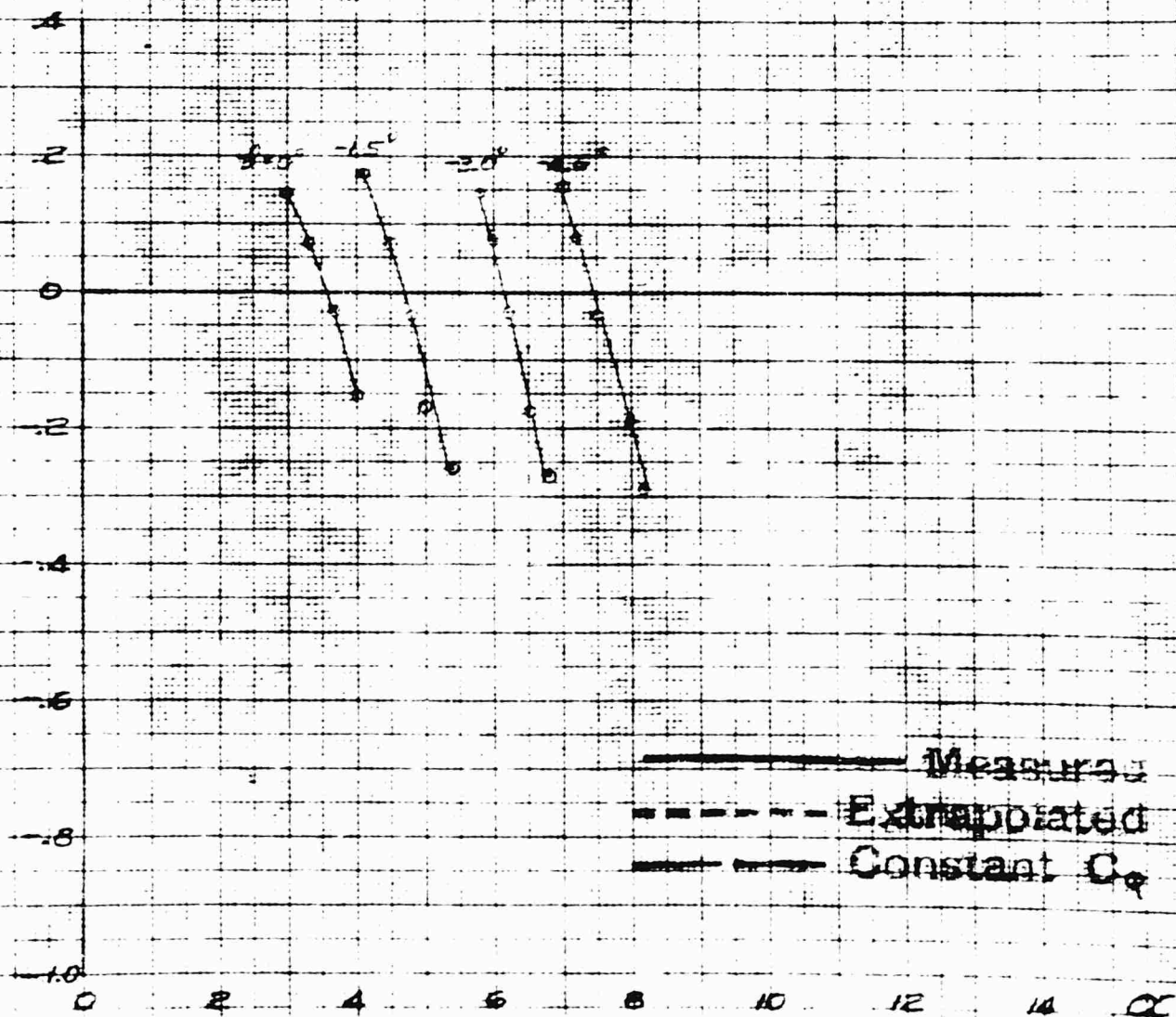
$\alpha = 0^\circ$

--- Measured
--- Extrapolated
--- Constant C_d

C_D VS α

UNVAL. C.T. '49 TESTS
WITHOUT HUB DRAG

B.

 $\mu = 1.25$ $10^3 C_D$ 

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C_p vs CC

ANAL OCT 23 1975
WITHOUT HLR TRANS

B.

$10^3 C_p$

4
2
0
-2
-4
-6
-8
-10

0 2 4 6 8 10 12 14 CC

Measured
Extrapolated
Constant C_p

KEUFFEL & ESSER CO.

No. 319 14 Millimeter, 5 mm lines recorded on lines heavy

C_D VS α

FINAL OCT 49 TESTS
WITHOUT HUB DRAG

C.

$\mu = 2.0$

$10^3 C_D$

4

2

0

-2

-4

-6

-8

-10

0

2

4

6

8

10

12

14

α

0°

-1.5°

-3.0°

-4.5°

Measured
Extrapolated
Constant C_D

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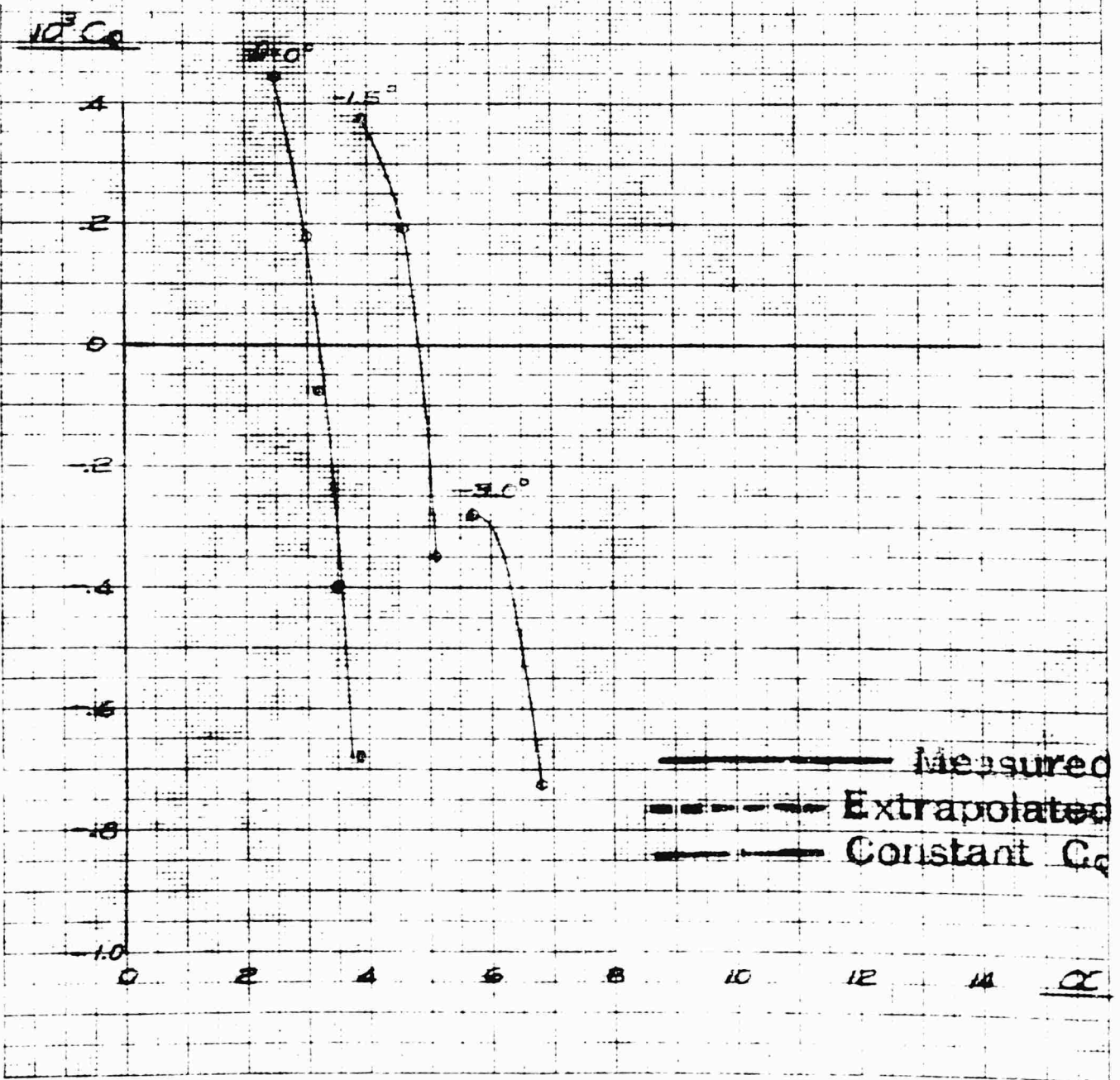
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C_D vs α

WVAL OCT '49 TESTS
WITHOUT HUB DRAG

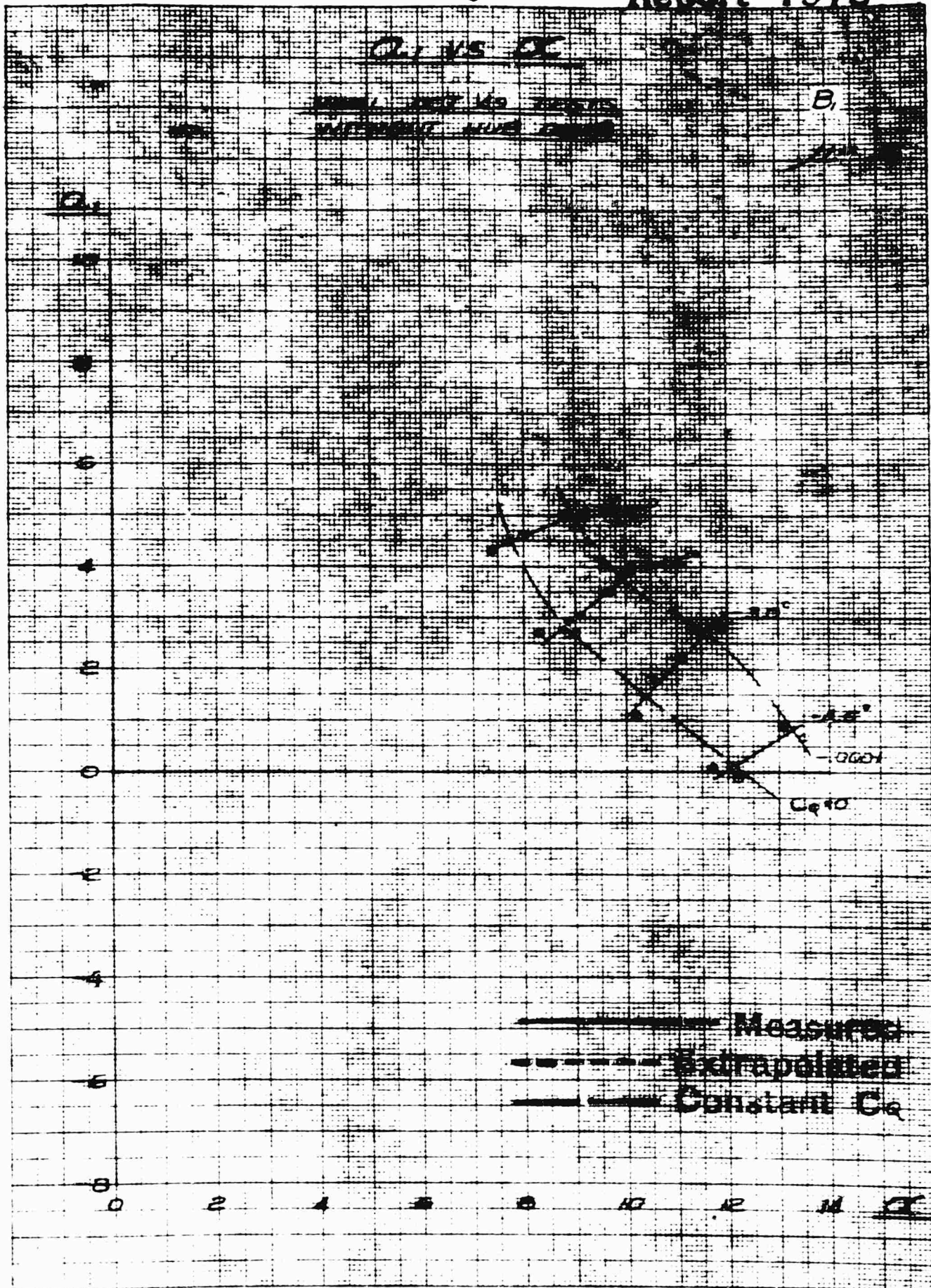
B

$\lambda = 2.5$



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KEUFFEL & ESSER CO.

No. 3-9-14 Miller-Press, 5 mm lines vertical, 10 mm lines heavy

12-2

Q_L VS α

MINIATURE TESTS
WITHOUT HULL DAMAGE

E_1

$\mu = 1.0$

Q_L

10

8

6

4

2

0

-2

-4

-6

-8

-10

-12

-14

-16

-18

-20

-22

-24

-26

-28

-30

-32

-34

-36

-38

-40

-42

-44

-46

-48

-50

0

2

4

6

8

10

12

14

16

18

20

22

24

26

28

30

32

34

36

38

40

42

44

46

48

50

52

54

56

58

60

0

2

4

6

8

10

12

14

16

18

20

22

24

26

28

30

32

34

36

38

40

42

44

46

48

50

52

54

56

58

60

0

2

4

6

8

10

12

14

16

18

20

22

24

26

28

30

32

34

36

38

40

42

44

46

48

50

52

54

56

58

60

0

2

4

6

8

10

12

14

16

18

20

22

24

26

28

30

32

34

36

38

40

42

44

46

48

50

52

54

56

58

60

0

2

4

6

8

10

12

14

16

18

20

22

24

26

28

30

32

34

36

38

40

42

44

46

48

50

52

54

56

58

60

0

2

4

6

8

10

12

14

16

18

20

22

24

26

28

30

32

34

36

38

40

42

44

46

48

50

52

54

56

58

60

0

2

4

6

8

10

12

14

16

18

20

22

24

26

28

30

32

34

36

38

40

42

44

46

48

50

52

54

56

58

60

0

2

4

6

8

10

12

14

16

18

20

22

24

26

28

30

32

34

36

38

40

42

44

46

48

50

52

54

56

58

60

0

2

4

6

8

10

12

14

16

18

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34

36

38

40

42

44

46

48

50

52

54

56

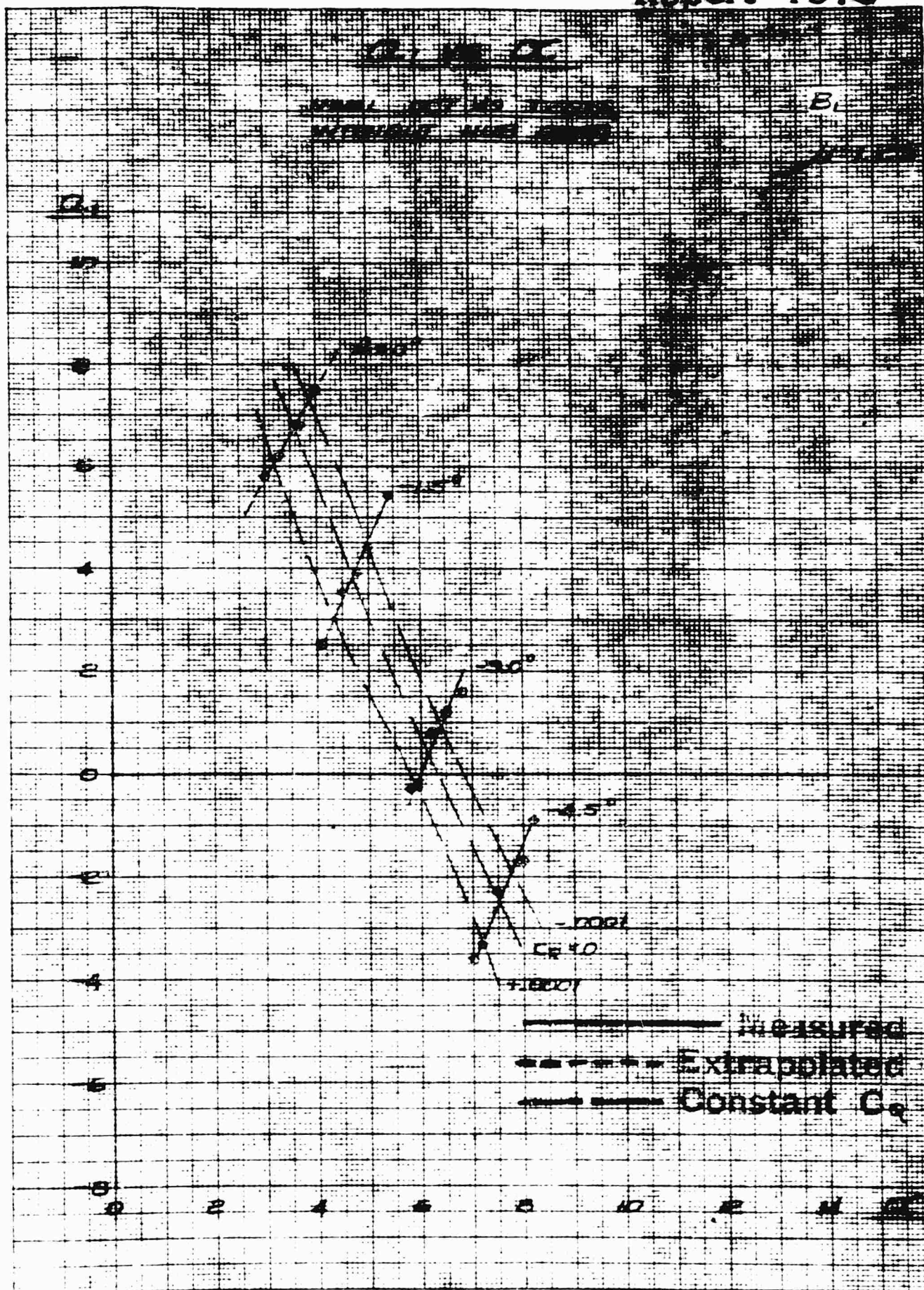
58

60

</

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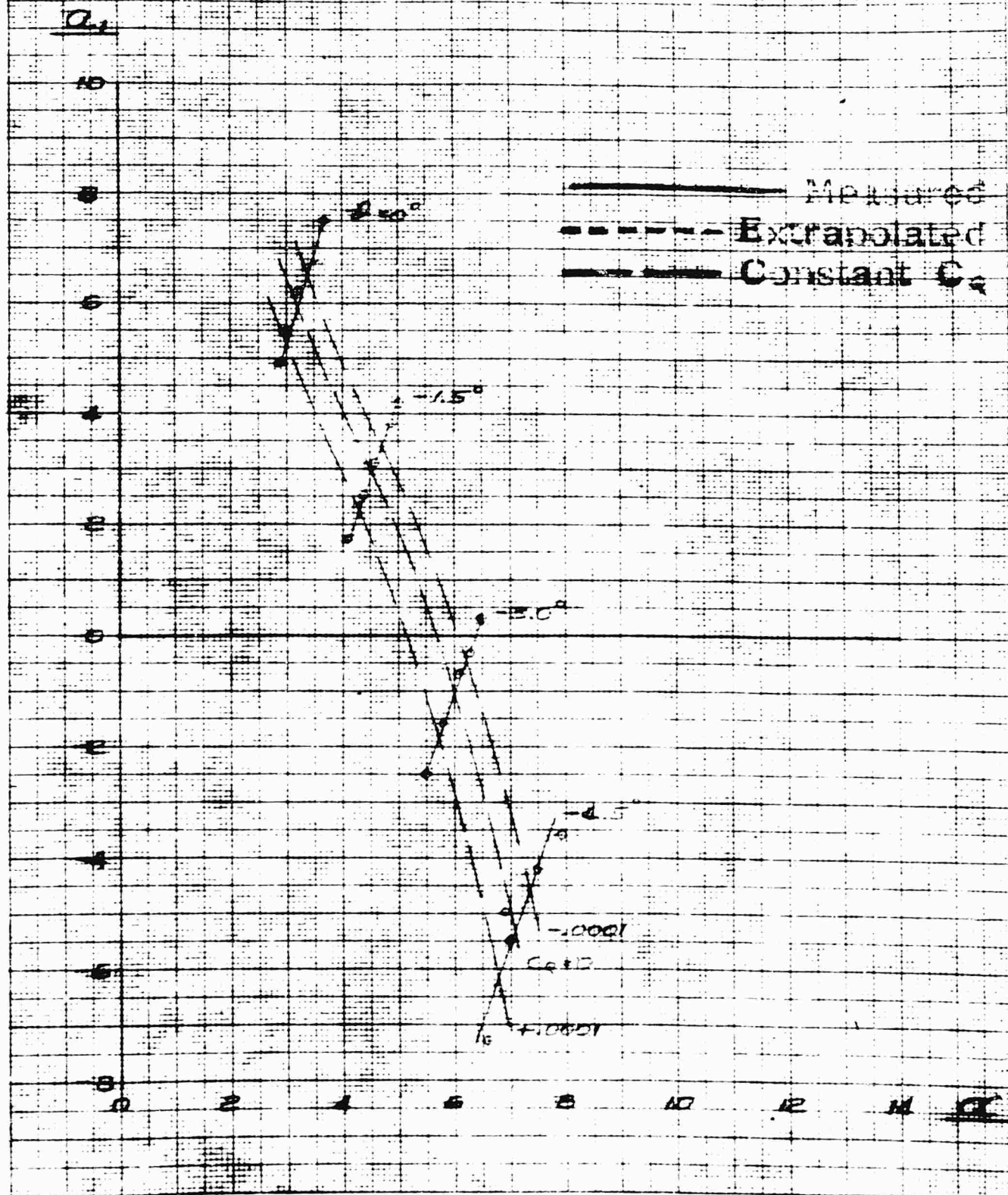
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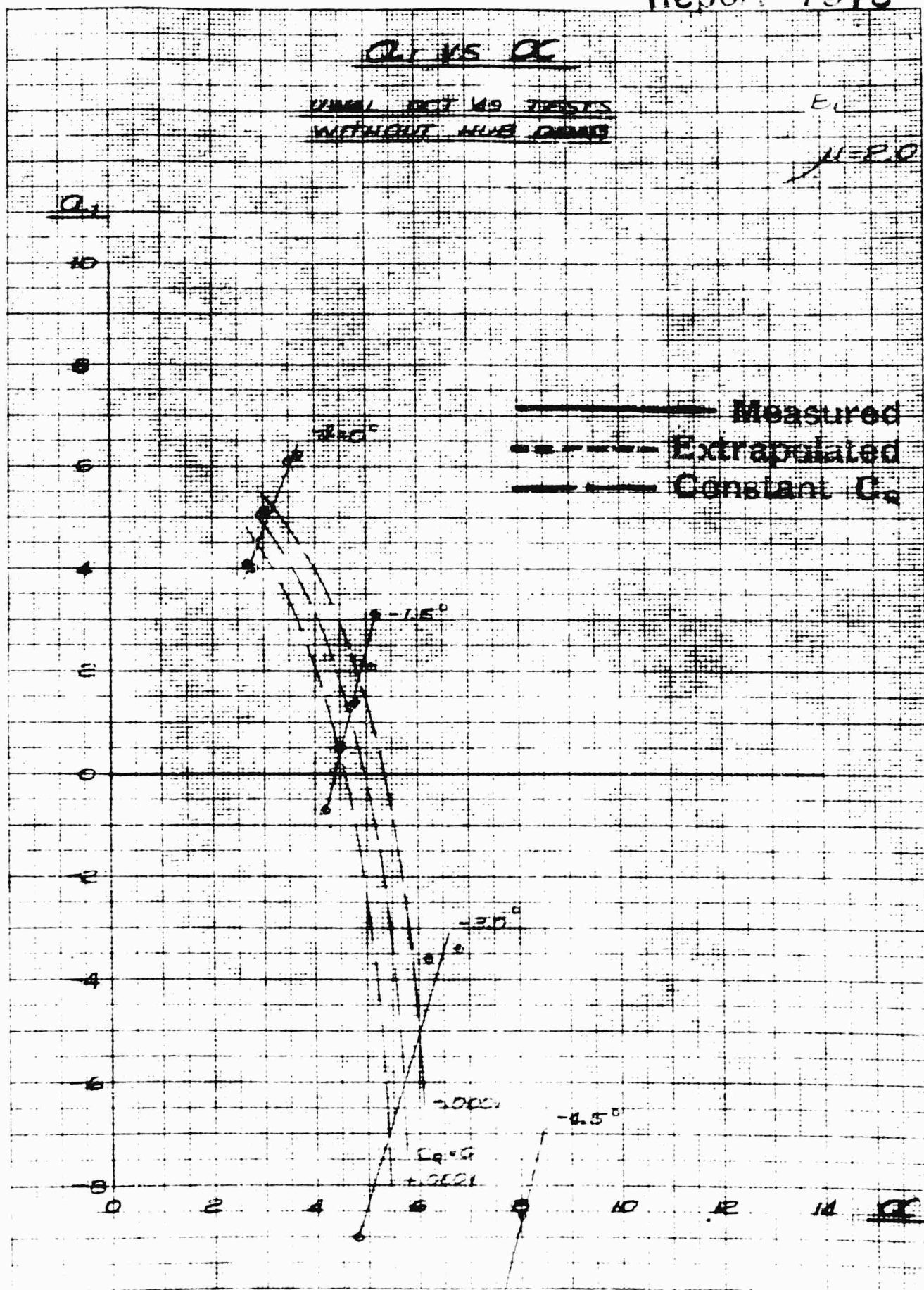


Q_1 VS OC

WIND TEST 149 TESTS
WITHOUT HUB DRAG

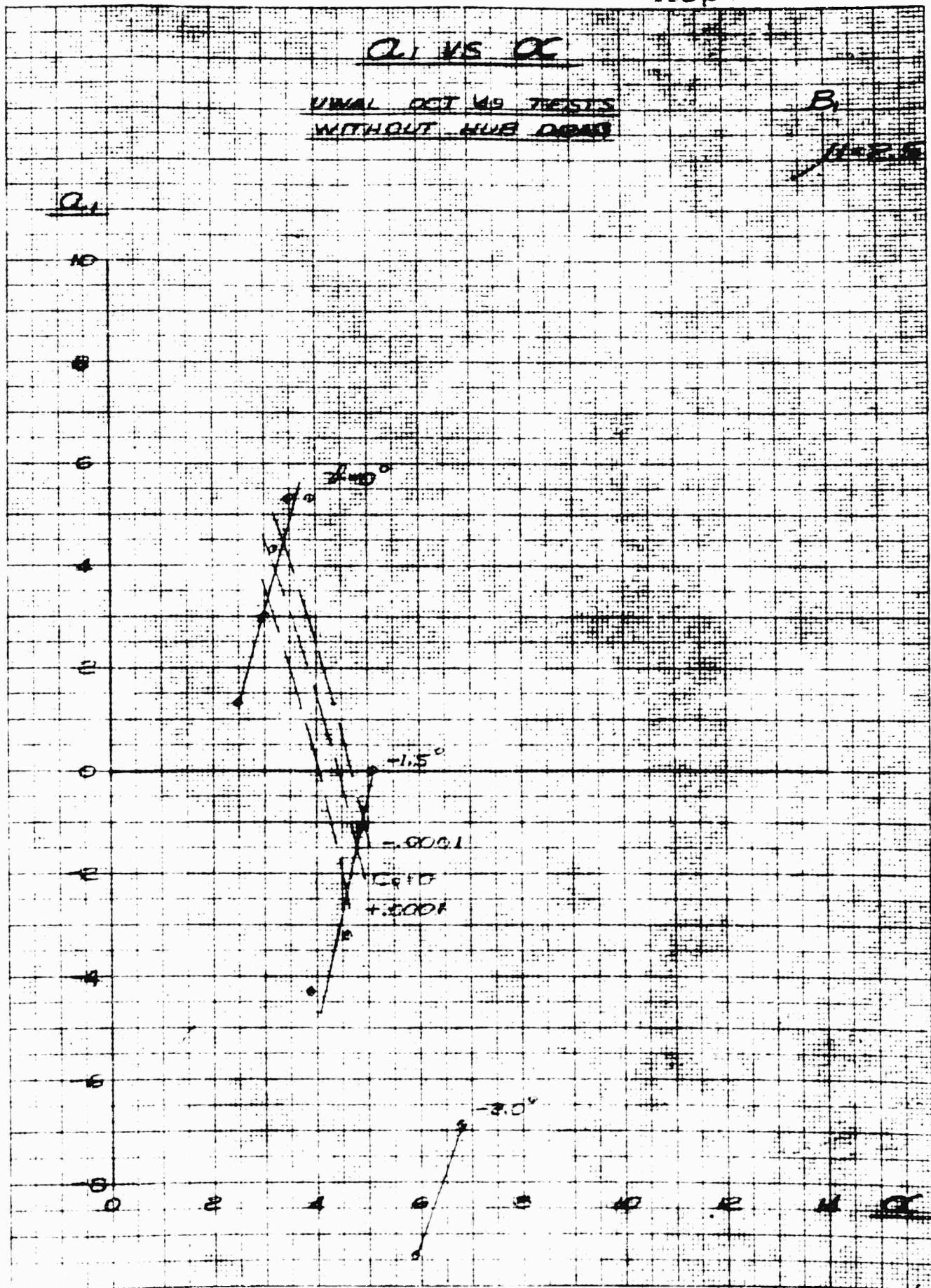
5,

 $U = 1.5$ 



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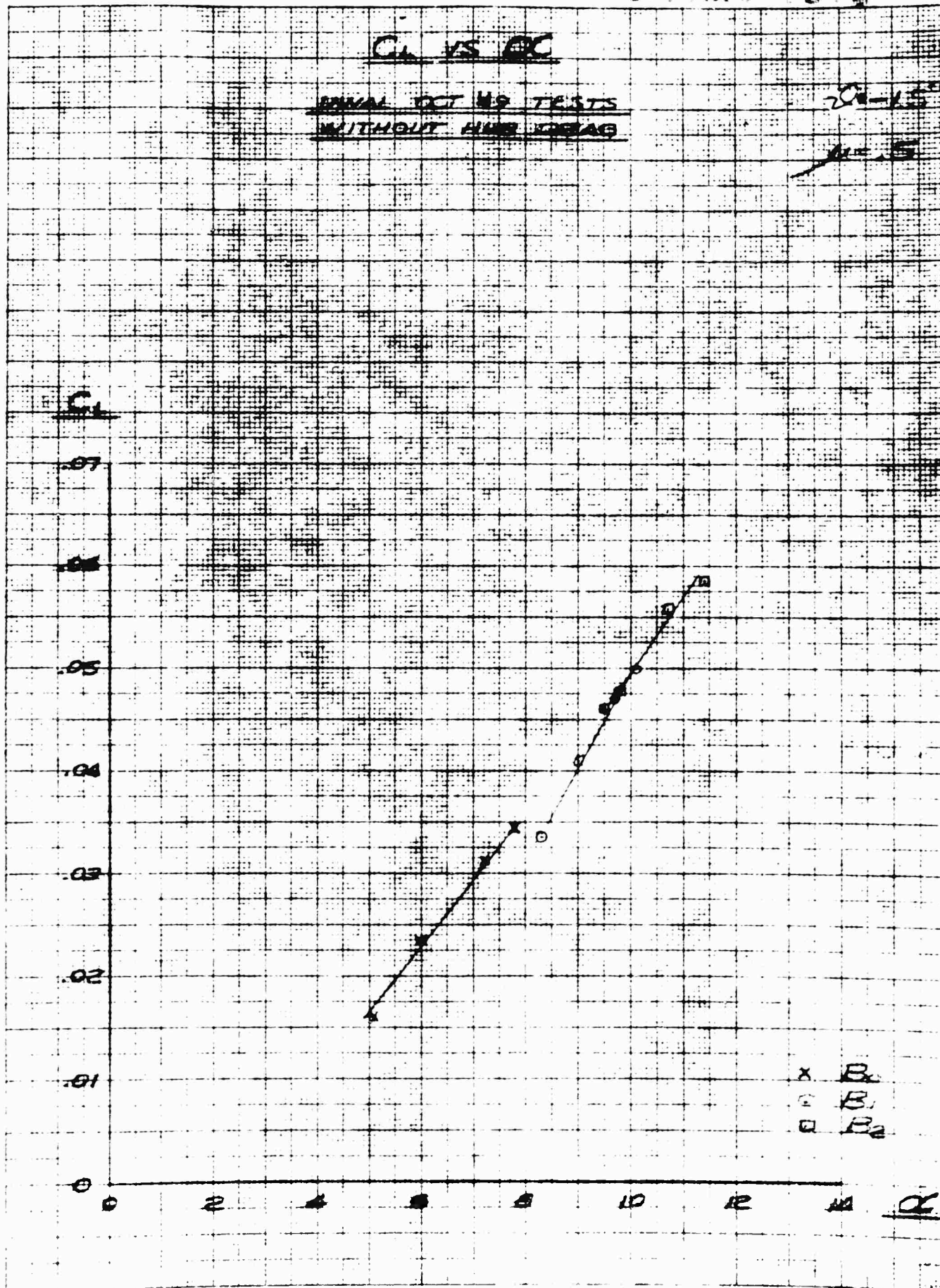


C_L VS Q_C

ANAL OCT 49 TESTS
WITHOUT HUB DEAG

20-15

4-5



CONFIDENTIAL

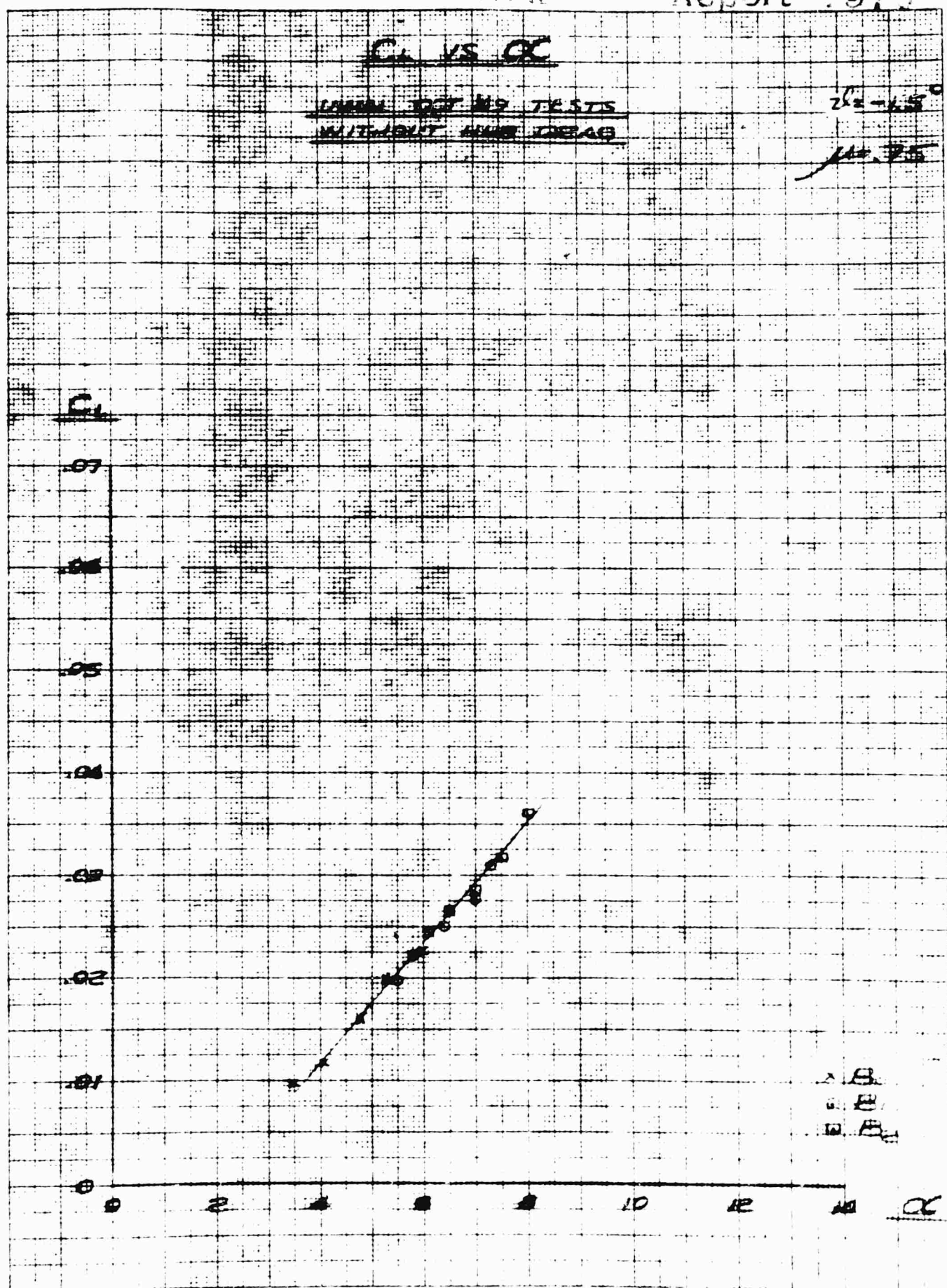
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CL VS CC

DATA SET NO. TESTS
WITHOUT AND DEAG

$2\sigma = 1.5^\circ$

$\mu = 75$



B
B
B

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Form 319
Report 1975

CL VS OC

ANAL OCT 40 TESTS
WITHOUT HUB LINES

$\alpha = 1.5^\circ$

$\mu = 10$

CL

.07

.06

.05

.04

.03

.02

.01

0

OC

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12-12-49

KEUFFEL & ESSER CO

No 35914 Millimeter, 5 mm lines, accuracy, 0.1 mm heavy

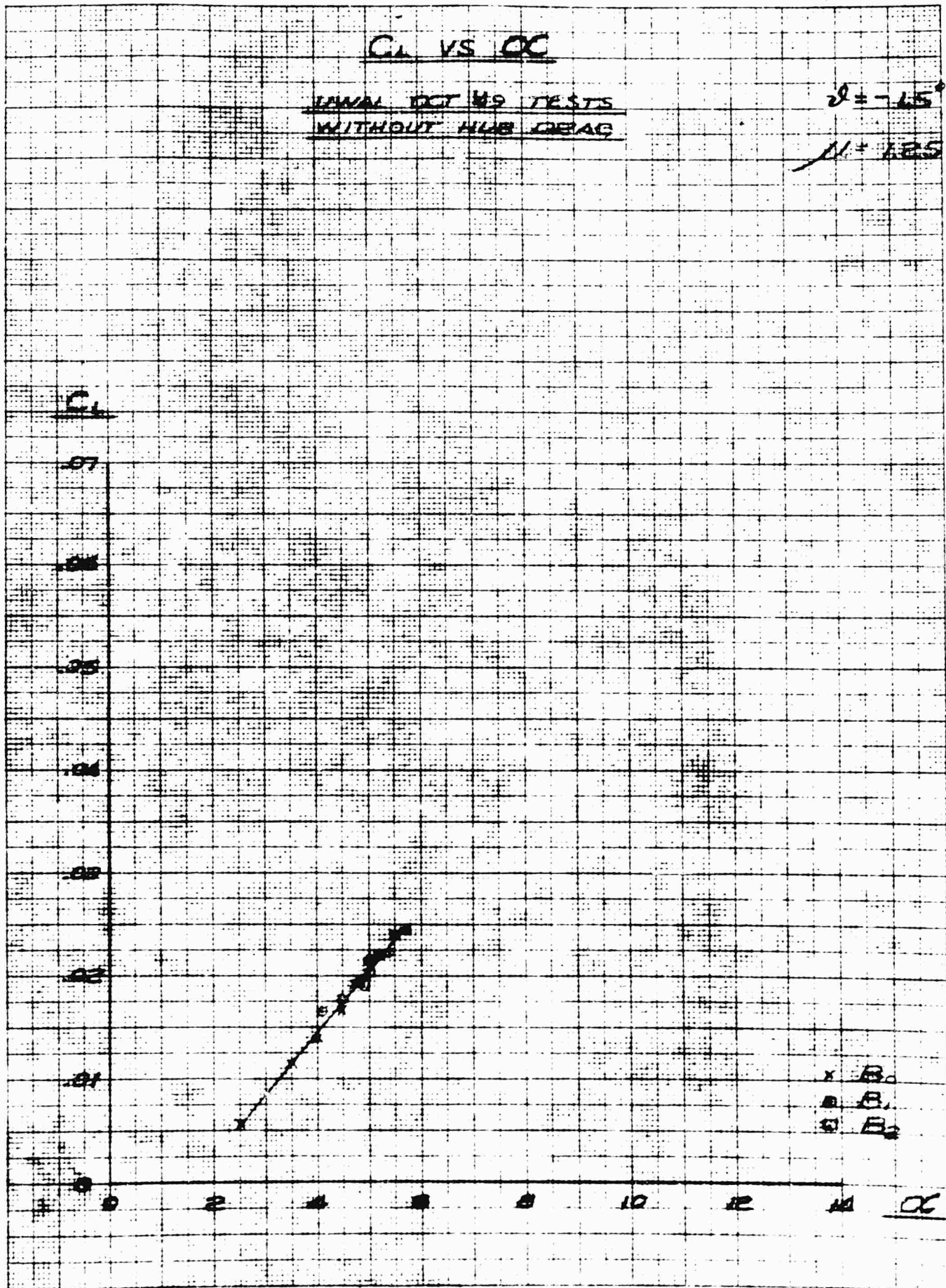
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CL VS OC

LAVAL OCT 49 TESTS
WITHOUT HUB DRAG

$\beta = -15^\circ$

$M = 1.25$



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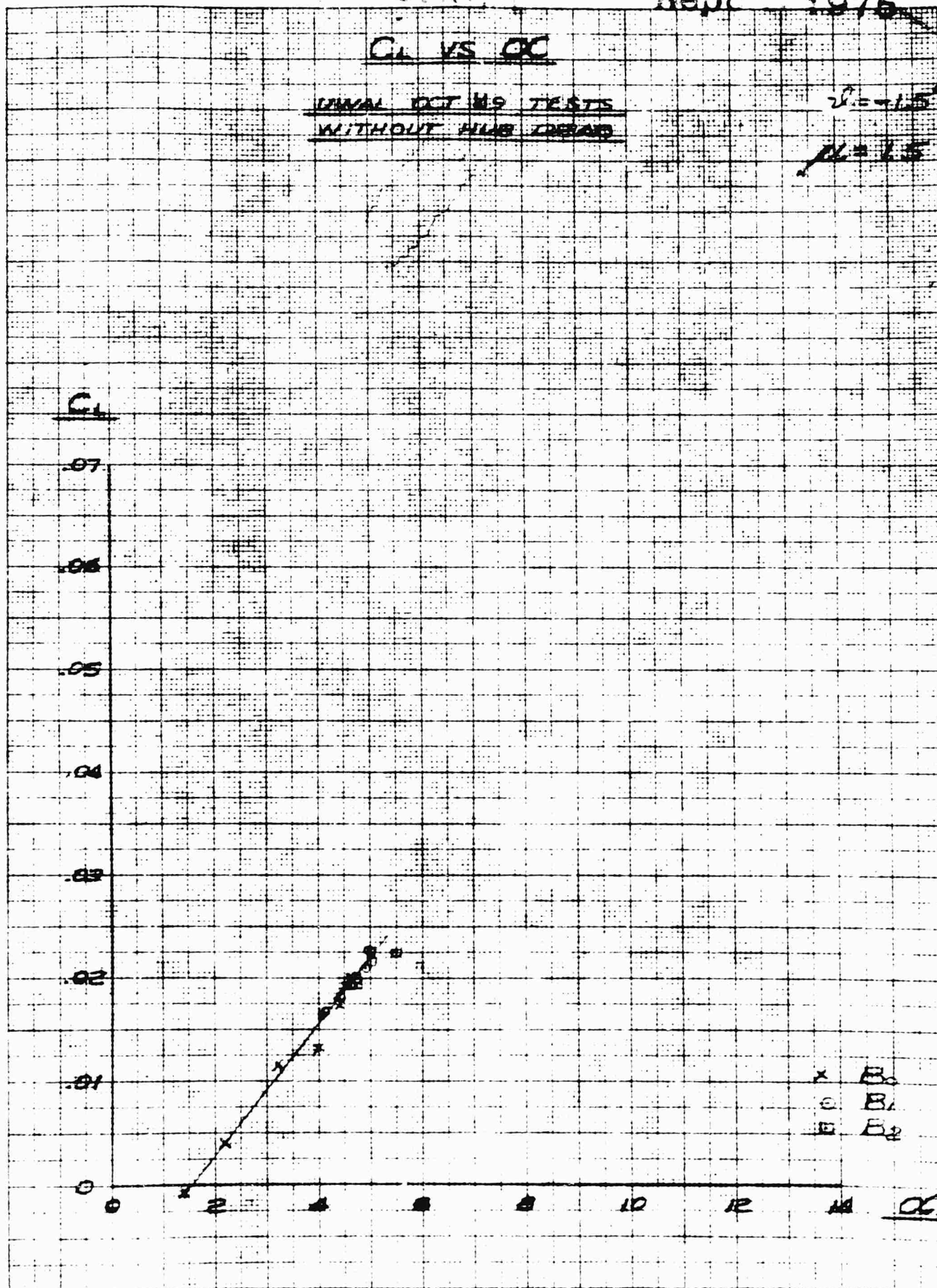
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CL VS CC

UNVAL OCT 149 TESTS
WITHOUT HUB DRAG

$\sigma = 1.5$

$\mu = 1.5$



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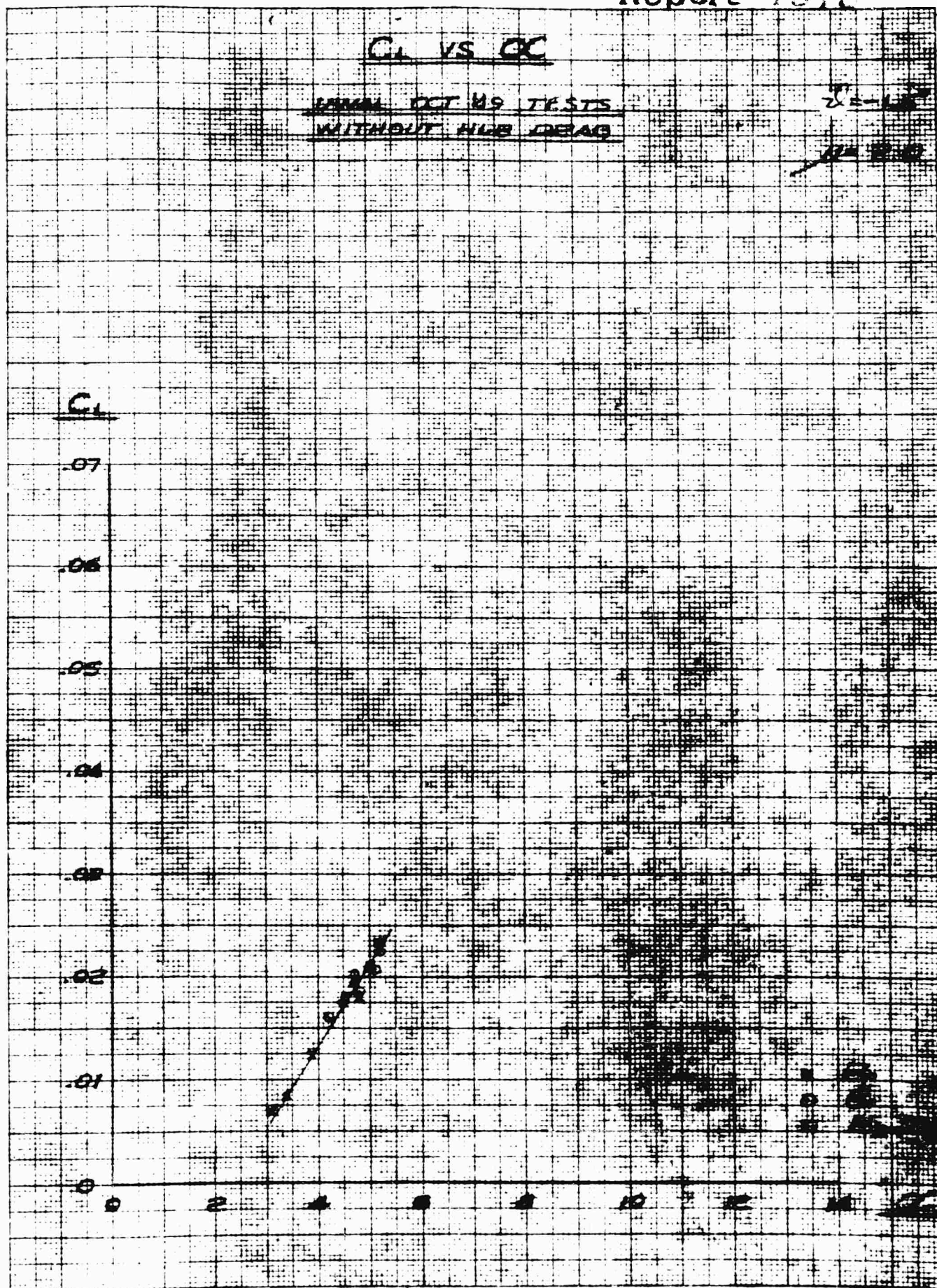
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CL VS CC

DATA OCT 49 TESTS
WITHOUT HLB DRAG

2E-10

1E-10



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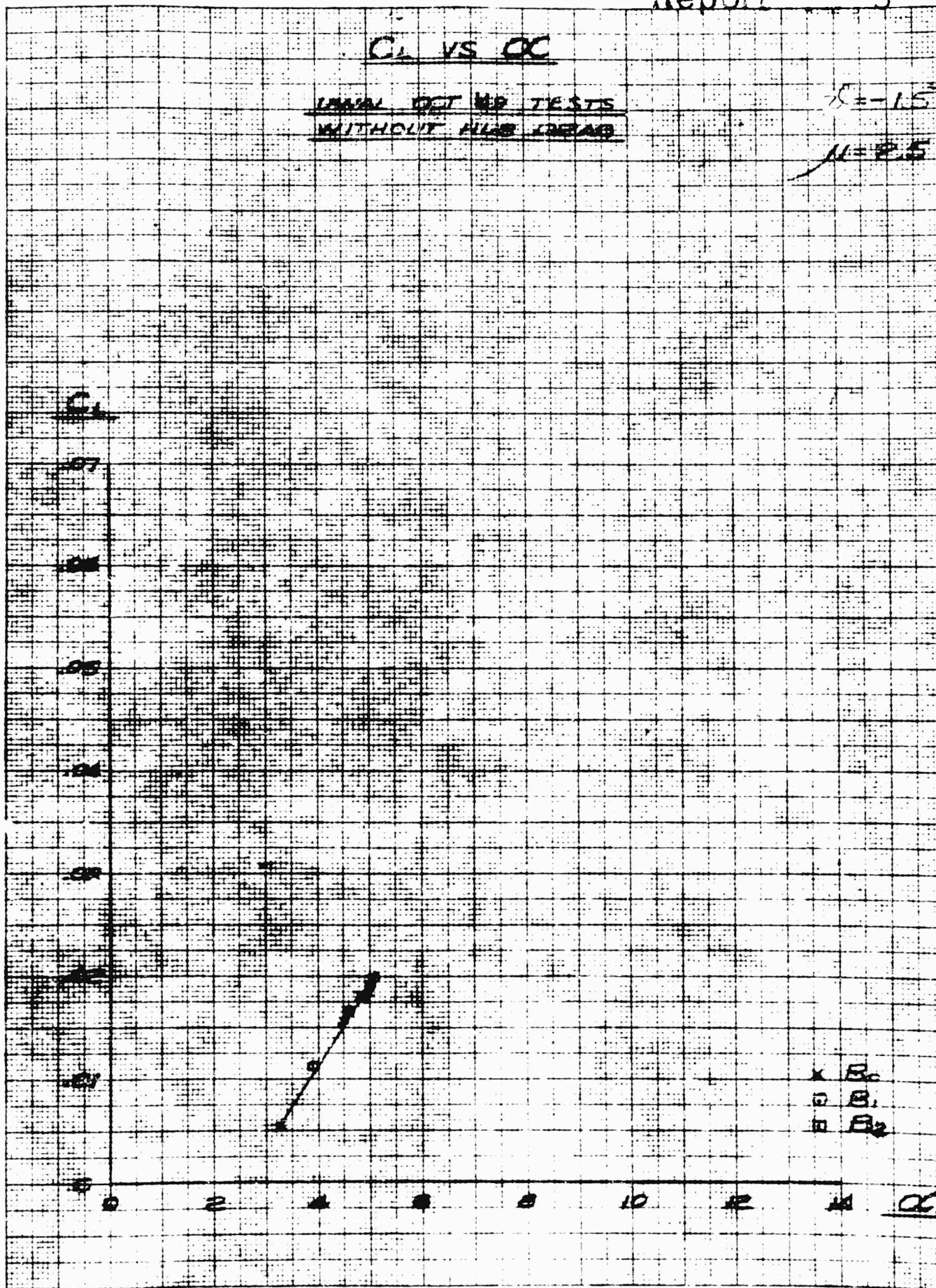
Report 5

CL VS OC

RAW OCT NR TESTS
WITHOUT HLB LEAD

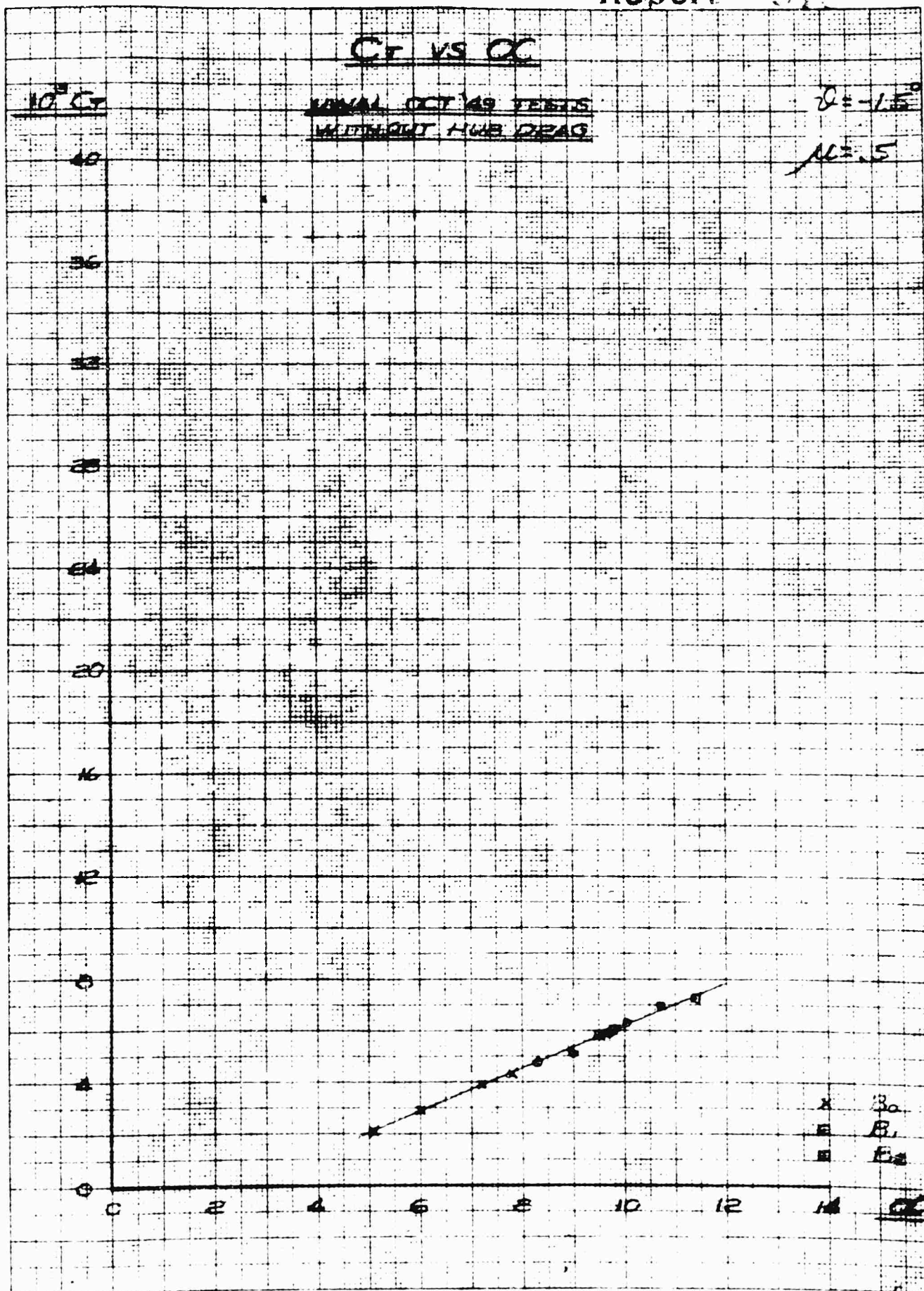
$\bar{X} = -1.5$

$n = 2.5$



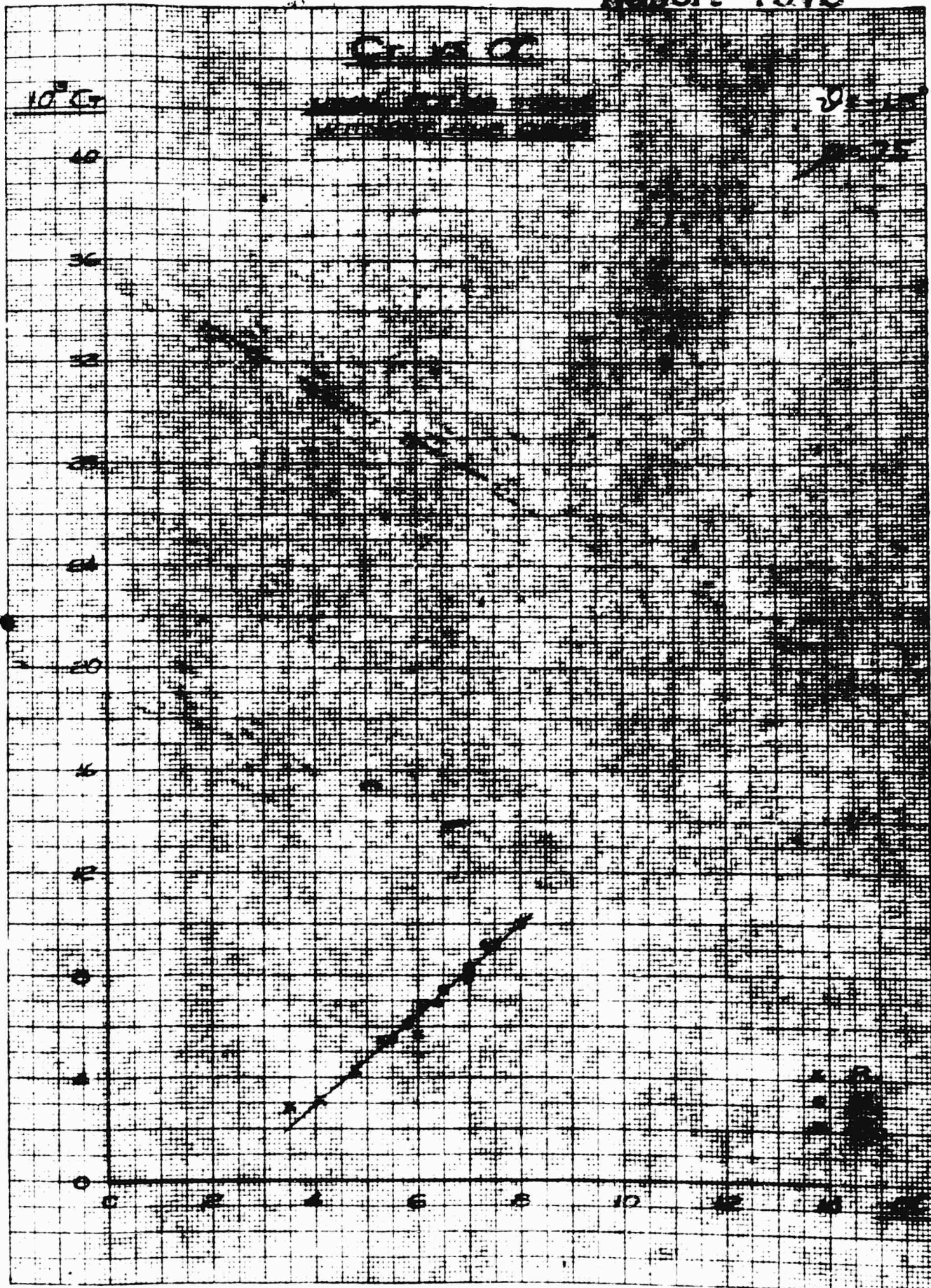
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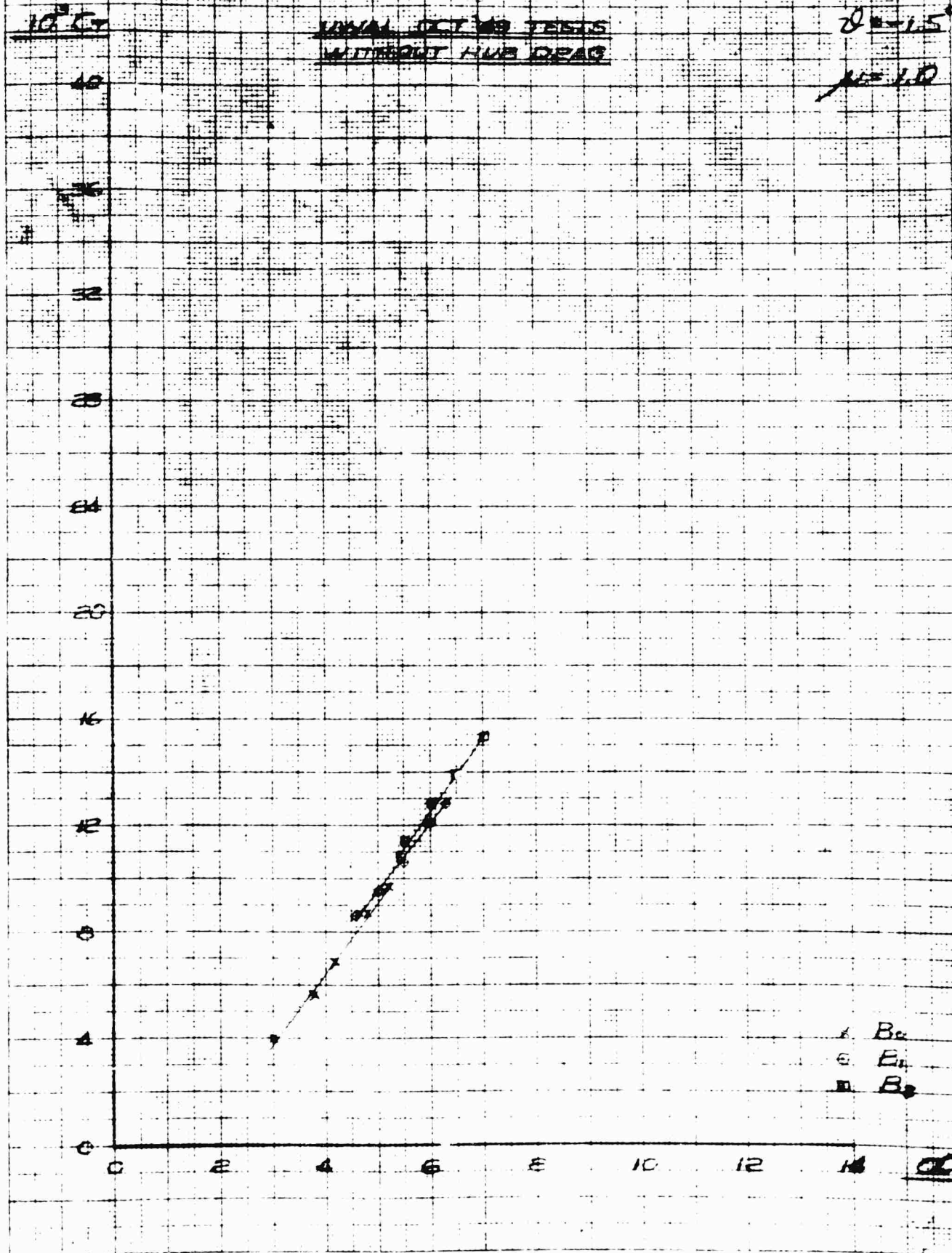


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CT VS CC



KTUPPEL & ESSER CO.

No. 10-11 Multi-pointing / combinations are used on lines heavy

UNCLASSIFIED

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327

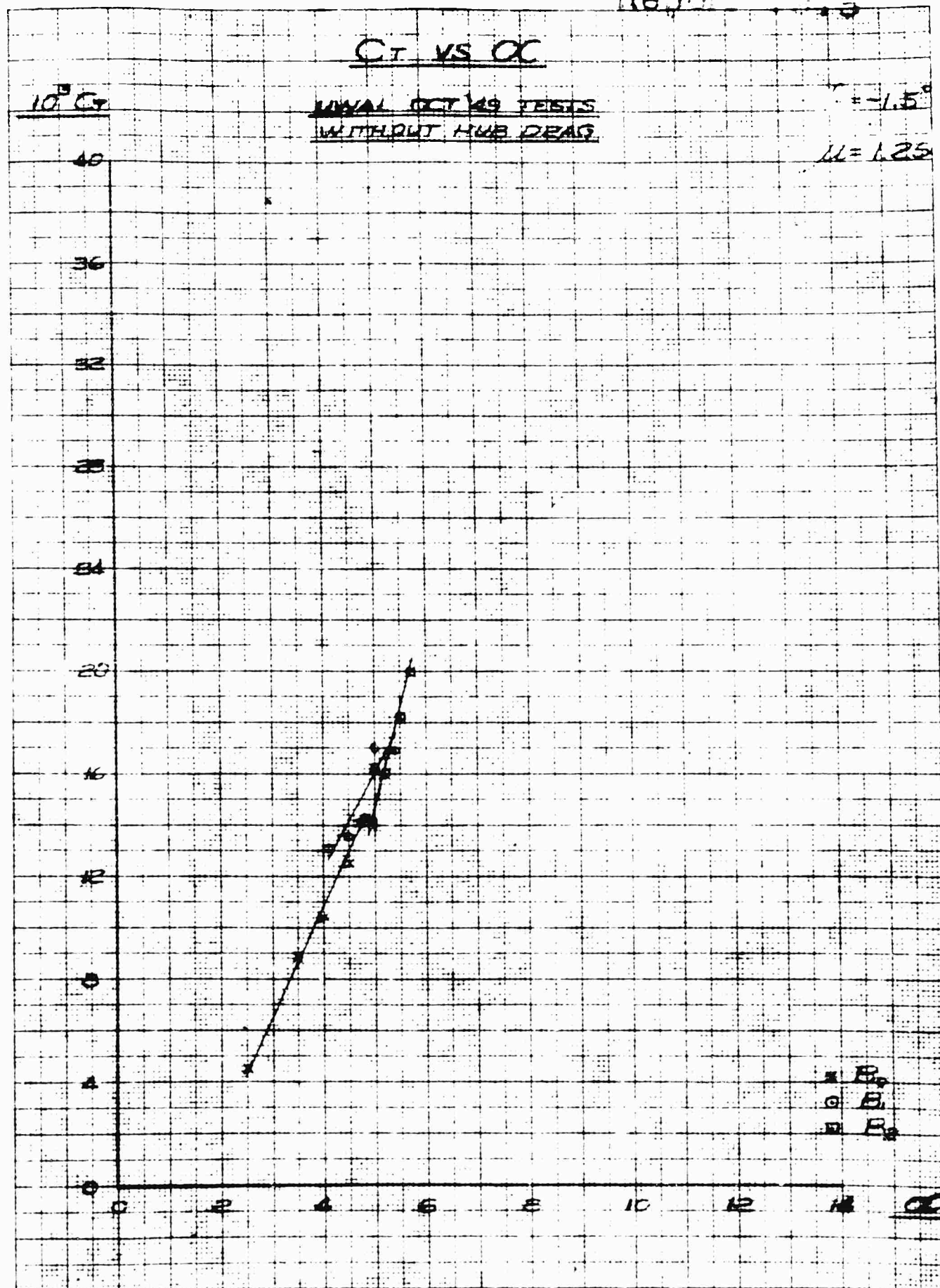
REPORT

CT VS OC

MINAL OCT 49 TESTS
WITHOUT HUB DRAG

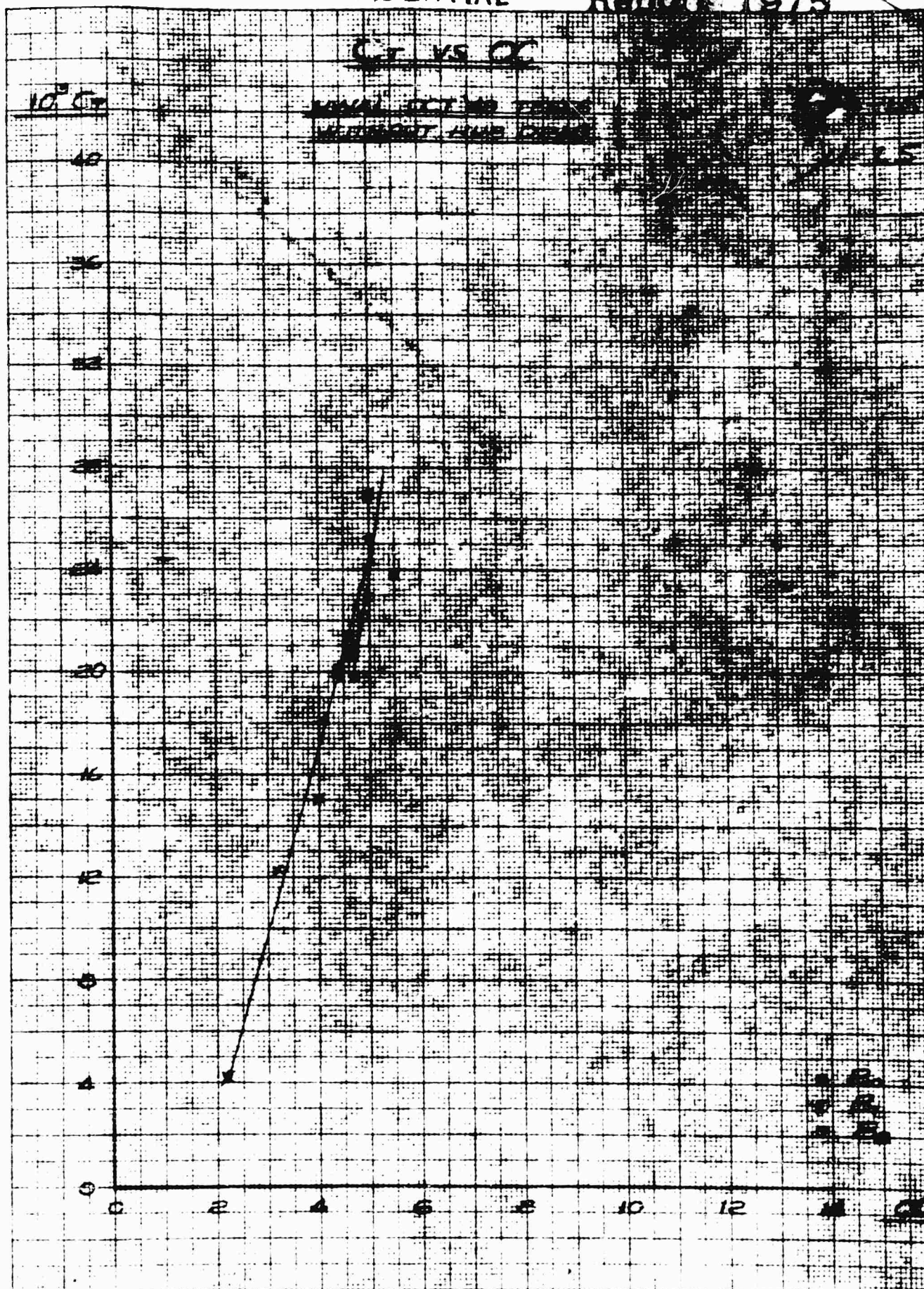
$\gamma = -1.5^\circ$

$\mu = 1.25$



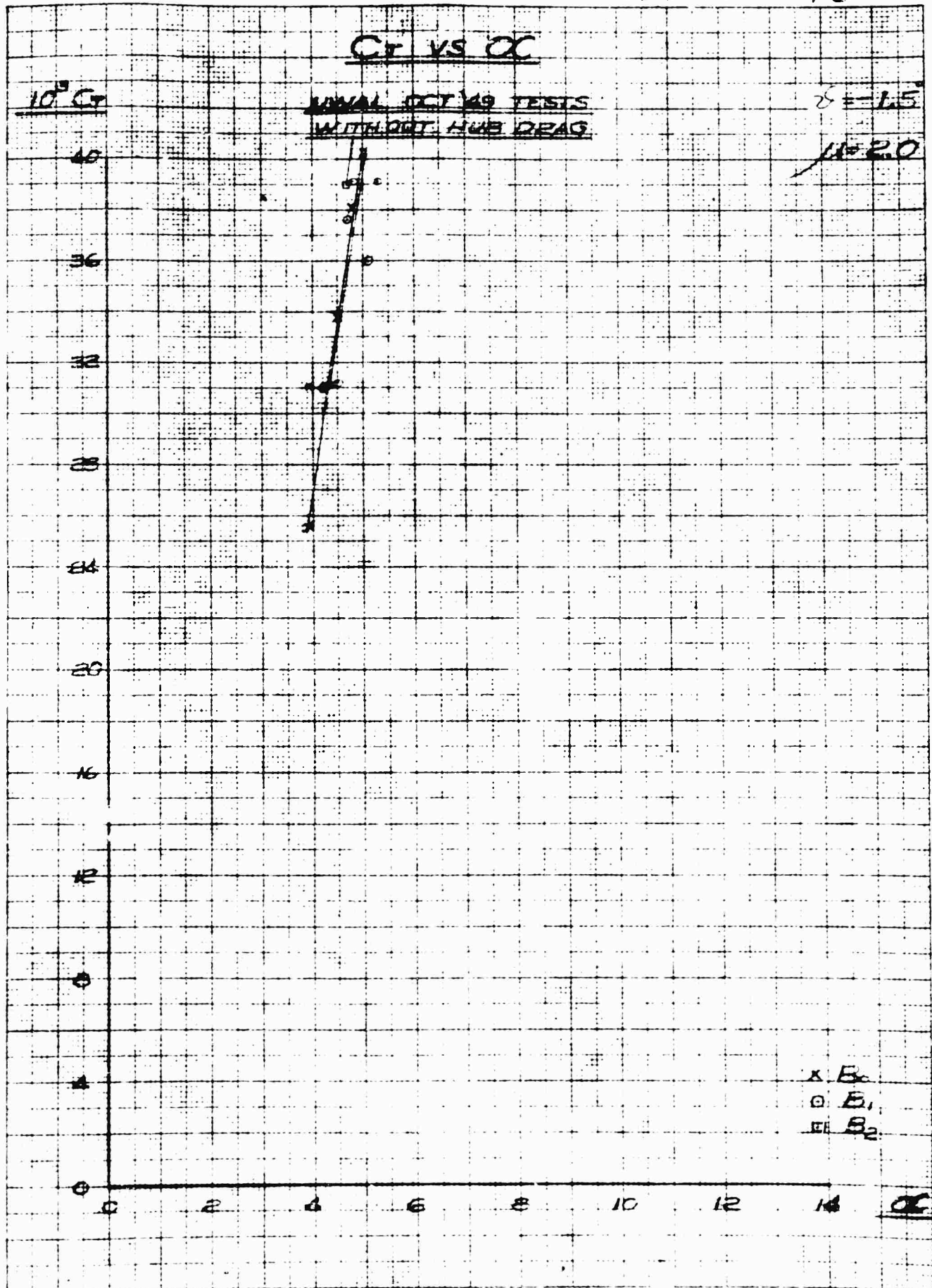
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Report

CT VS OC

10³ CT

UNVAL OCT 49 TESTS
WITHOUT HUB DRAG

$\theta = -1.5^\circ$

$\mu = 2.5$

4

6

8

52

44

0

2

4

6

8

10

12

14

OC

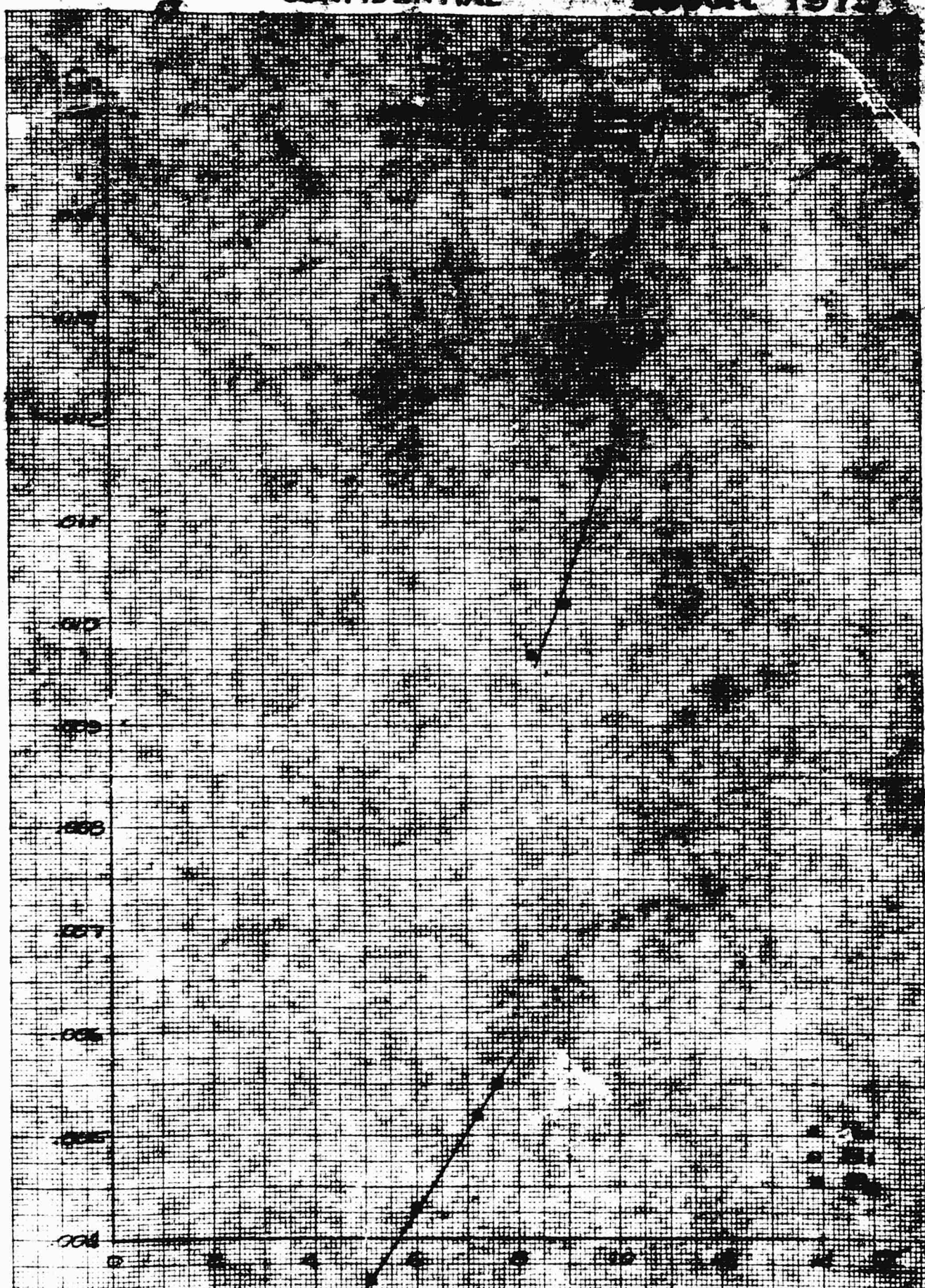
x B_0
□ B_1
□ B_2

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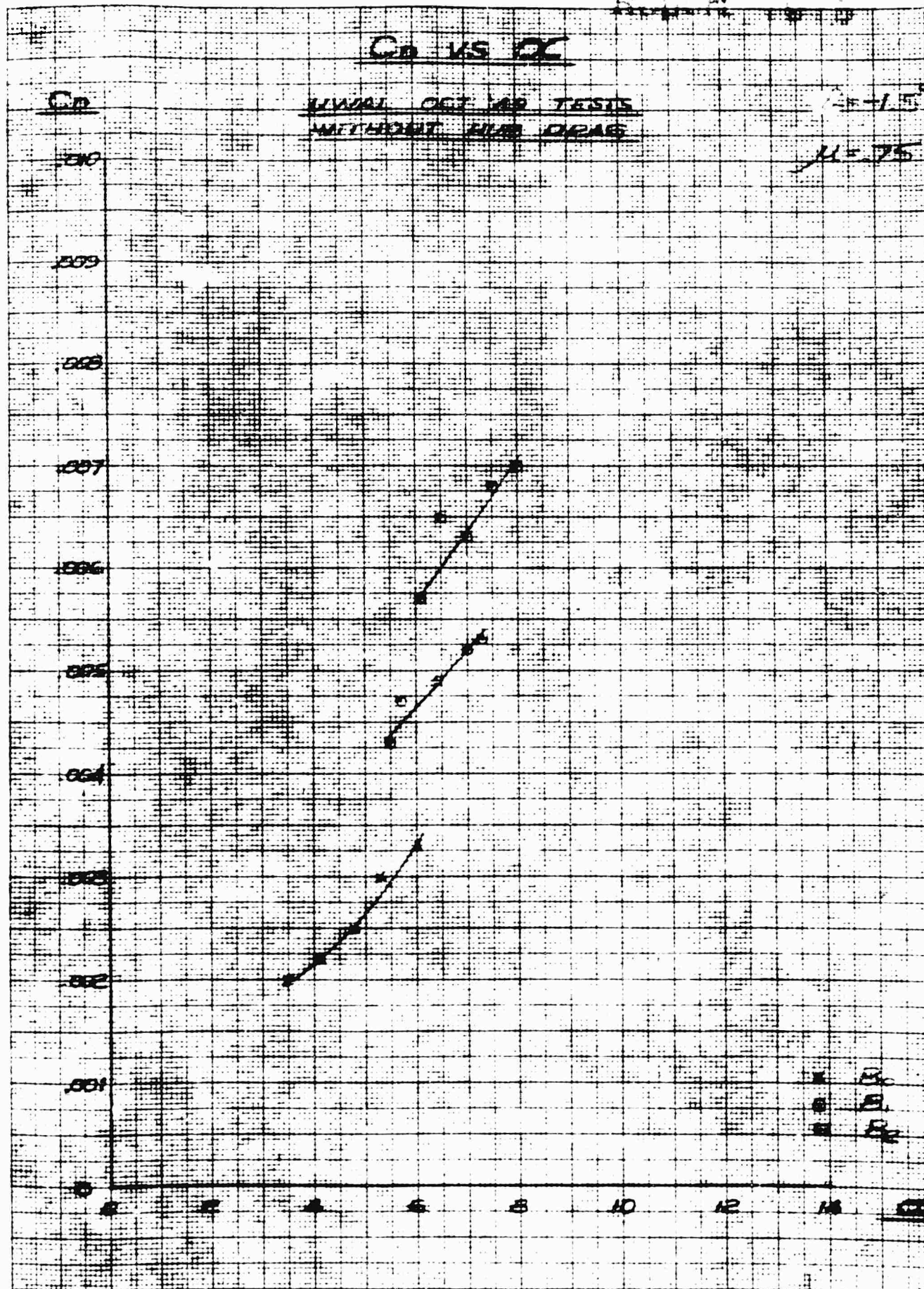
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Vertical axis label: $\log_{10} \frac{1}{\rho} \frac{d\rho}{dt}$

Horizontal axis label: $\log_{10} \frac{1}{\rho} \frac{d\rho}{dt}$

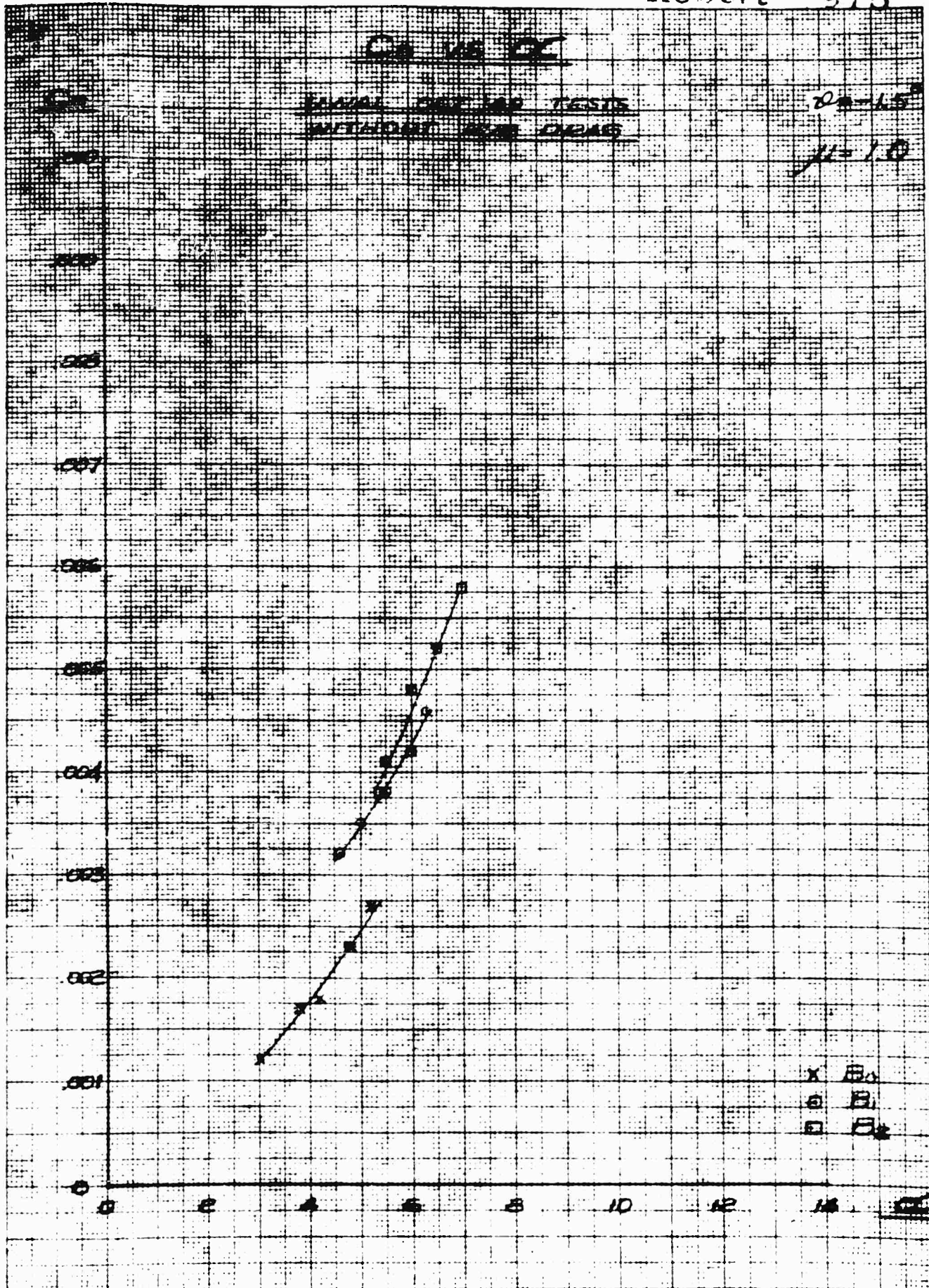


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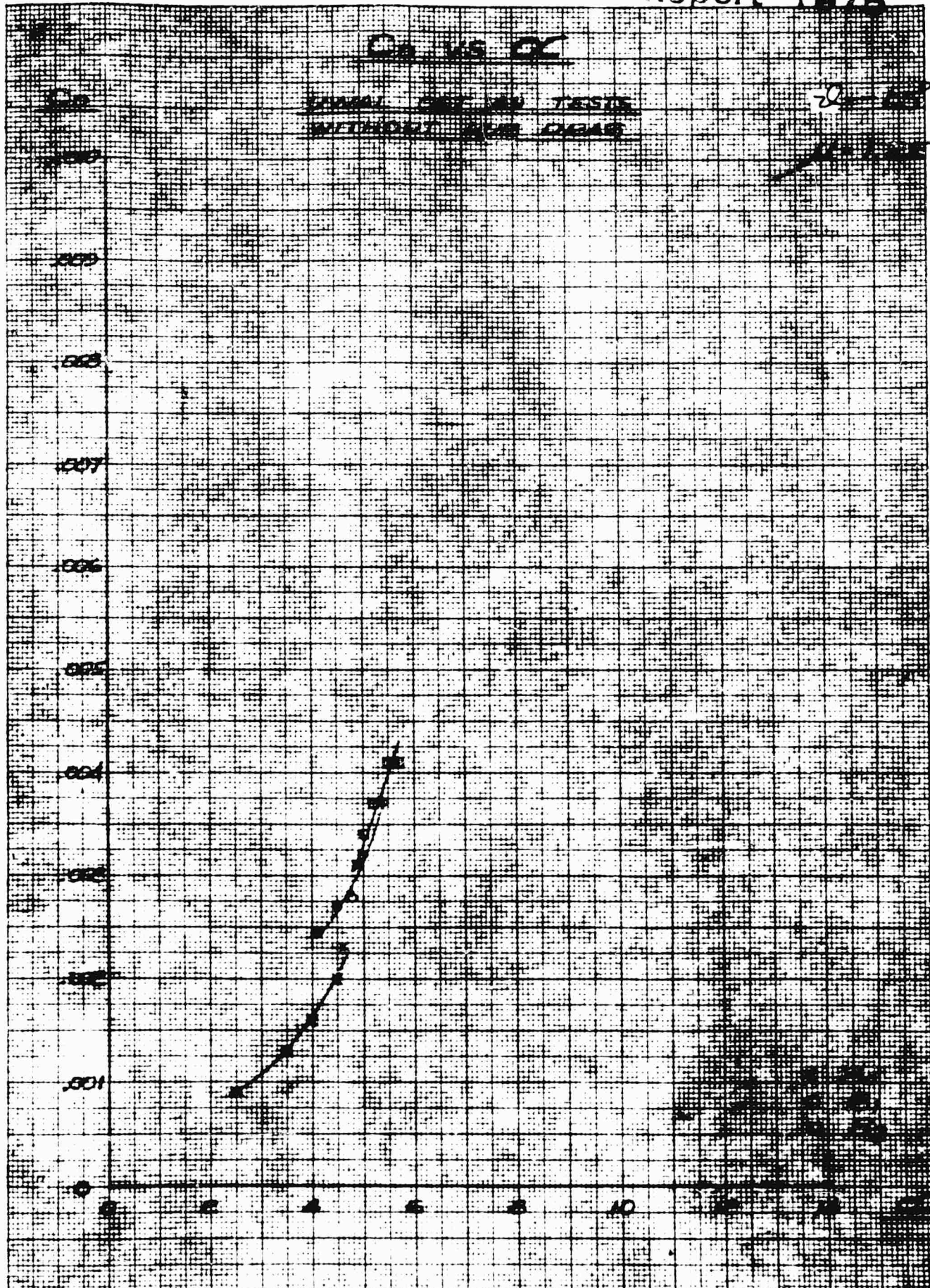
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KEUFFEL & ESSER CO.

No. 359 14. Millimeters 5 mm lines accented cm lines heavy

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12-13-49
98

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6/01/1975

C_D VS α

UNWAL OCT 140 TESTS
WITHOUT HUB DRAG

$\beta = +1.5$

$\mu = 1.5$

C_D

.010

.009

.008

.007

.006

.005

.004

.003

.002

.001

0

0

2

4

6

8

10

12

14

16

α

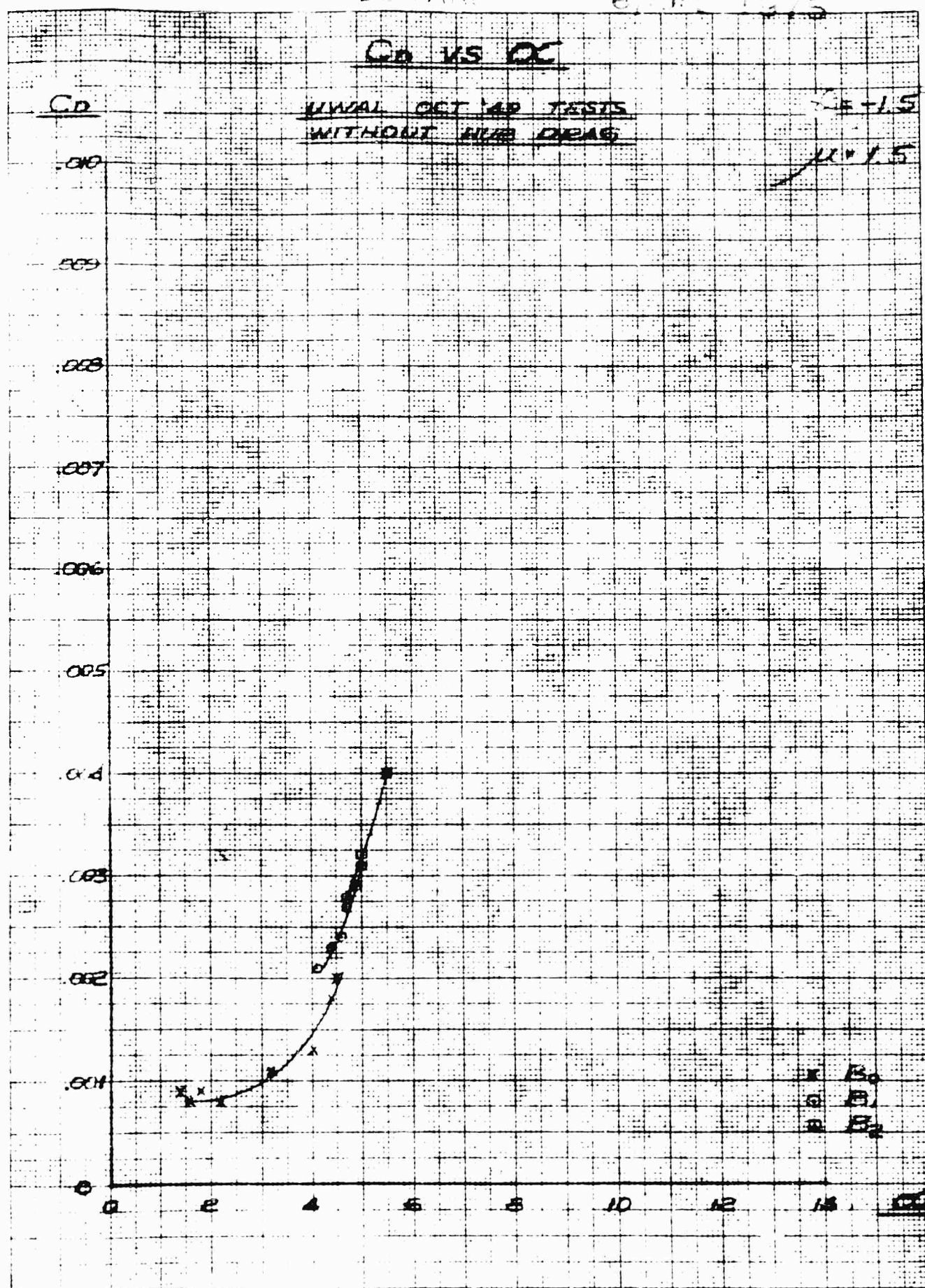
B_0

B_1

B_2

KEUFFEL & ESSER CO

No. 359-14, Millimeters: 5 min lines accented, cm lines heavy



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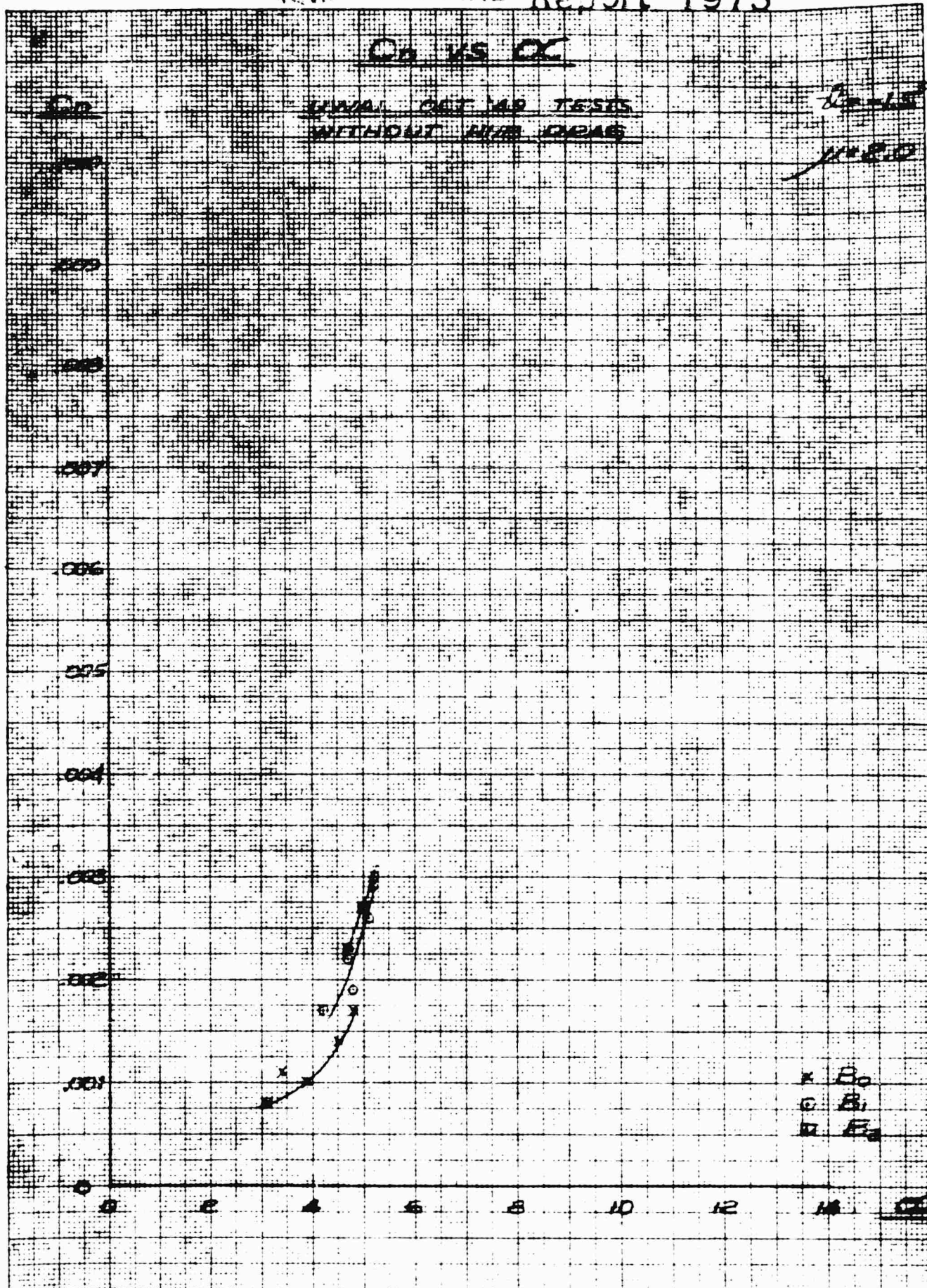
336
Report 1975

C_D VS C_X

UNVAL. OCT 149 TESTS
WITHOUT HIR. DRAG

$R = 1.5$

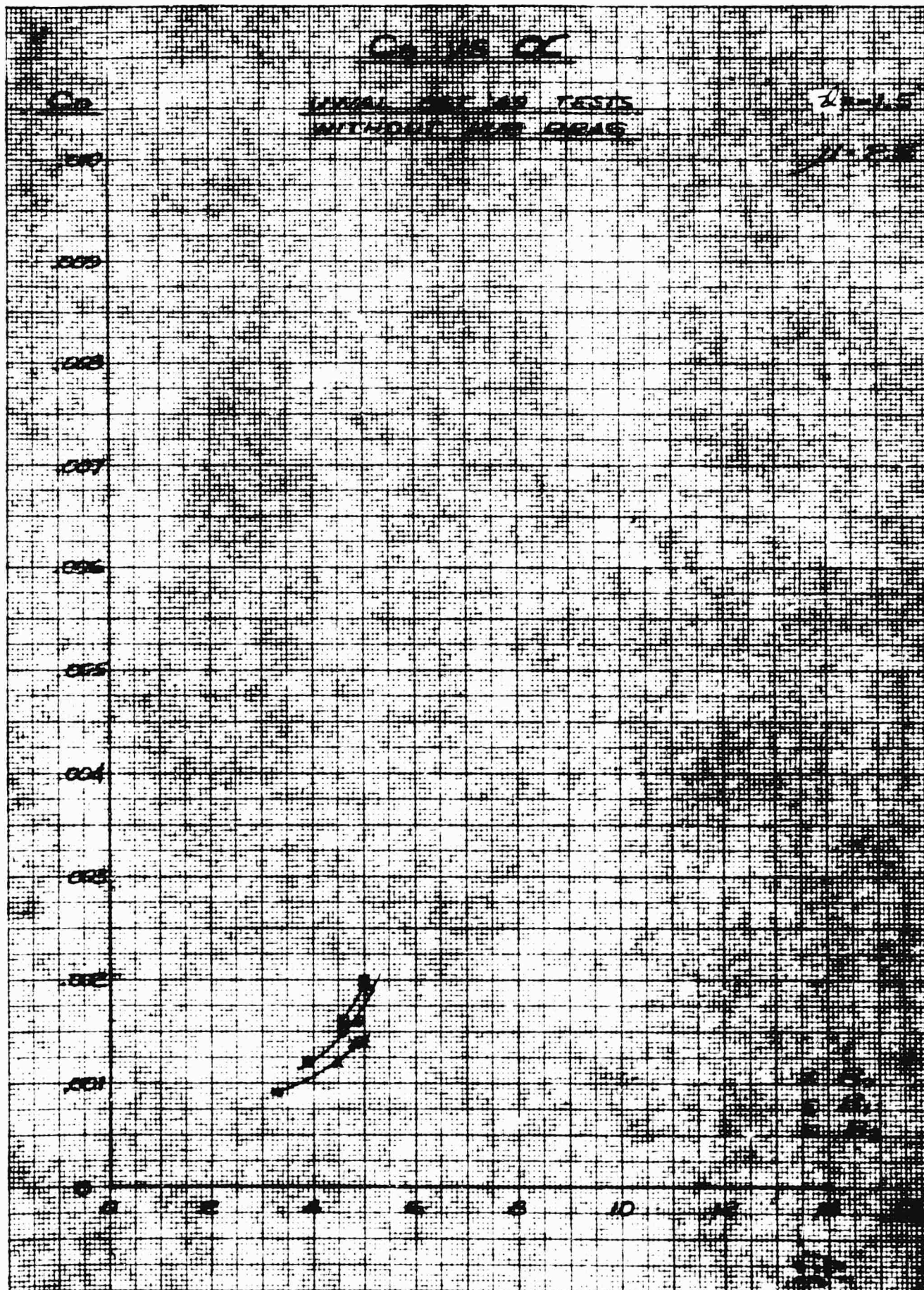
$\mu = 8.0$



x B_0
o B_1
□ B_2

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KEIFFEL & ESSER CO

No 319 14, Millimeters 5 mm lines accented, cm lines heavy

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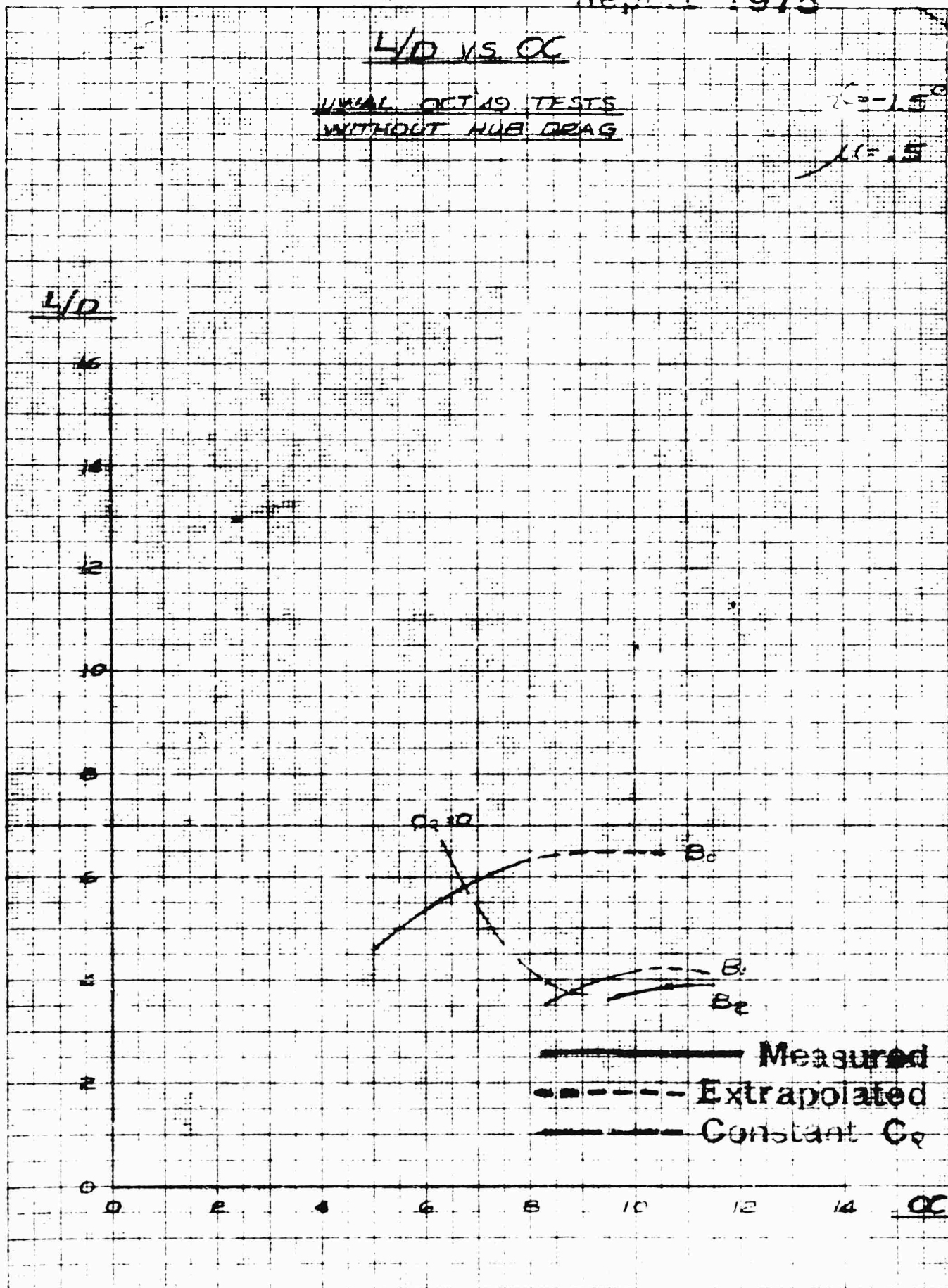
338
Report 1975

L/D vs. OC

UNIAL OCT 19 TESTS
WITHOUT HUB DRAG

$\alpha = -1.5^\circ$

$\alpha = 1.5^\circ$



KEUFFEL & ESSER CO.

No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

132

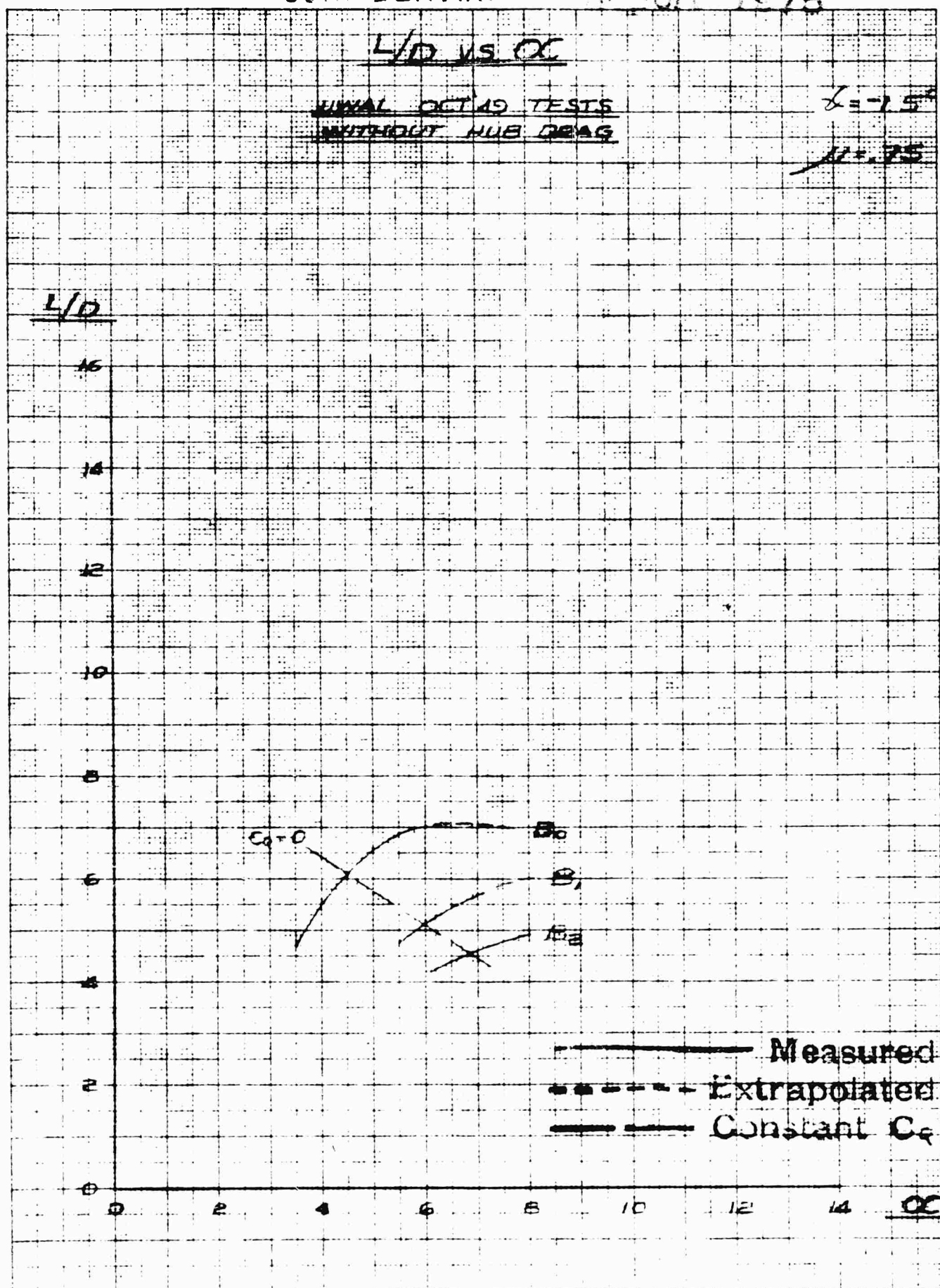
177

L/D VS α

~~UNUAL OCT 19 TESTS~~
~~WITHOUT HUB DRAG~~

2-15

THE UNIVERSITY OF CHICAGO PRESS



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L/D vs. OC

FINAL OCTAS TESTS
WITHOUT HUE DRAG

25-15

10-10

L/D

16

14

12

10

8

6

4

2

0

0

2

4

6

8

10

12

14

16

18

20

22

24

26

28

30

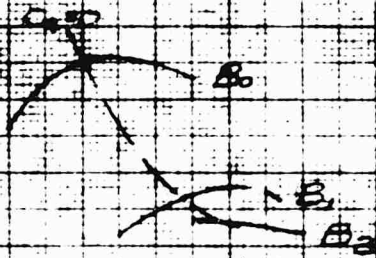
32

34

36

38

40



Measured
Extrapolated
Constant C_c

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17-13-49

10d

KIEPHEL & ESSER CO

No. 39.13 Millimeters, 5 mm lines, 10 mm lines, 10 mm lines

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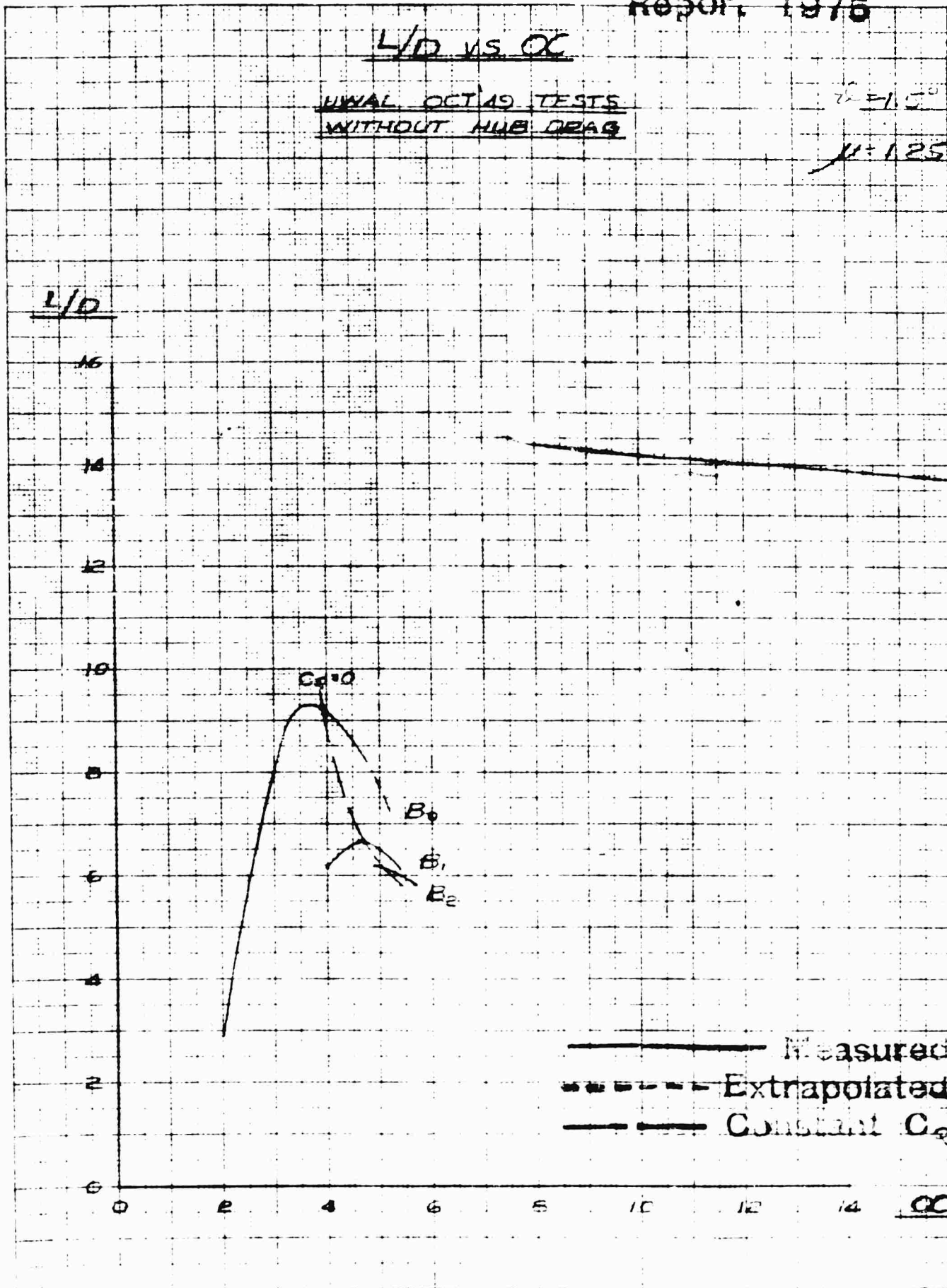
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L/D vs OC

UNVAL OCT 19 TESTS
WITHOUT HUB DRAG

$Re = 1.5 \times 10^5$

$M = 1.25$



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L/D vs OC

UNVAL OCT 49 TESTS
WITHOUT HUB DRAG

$\gamma = -1.5^\circ$

$\mu = 1.5$

L/D

16

14

12

10

8

6

4

2

0

$C_d = 0$

B_v

B_s

B_e

————— Measured
- - - - - Extrapolated
————— Constant C_d

0

2

4

6

8

10

12

14

OC

KEUFFEL & ESSER CO

No. 359-14 Millimeter, 5 mm lines are used on line heavy

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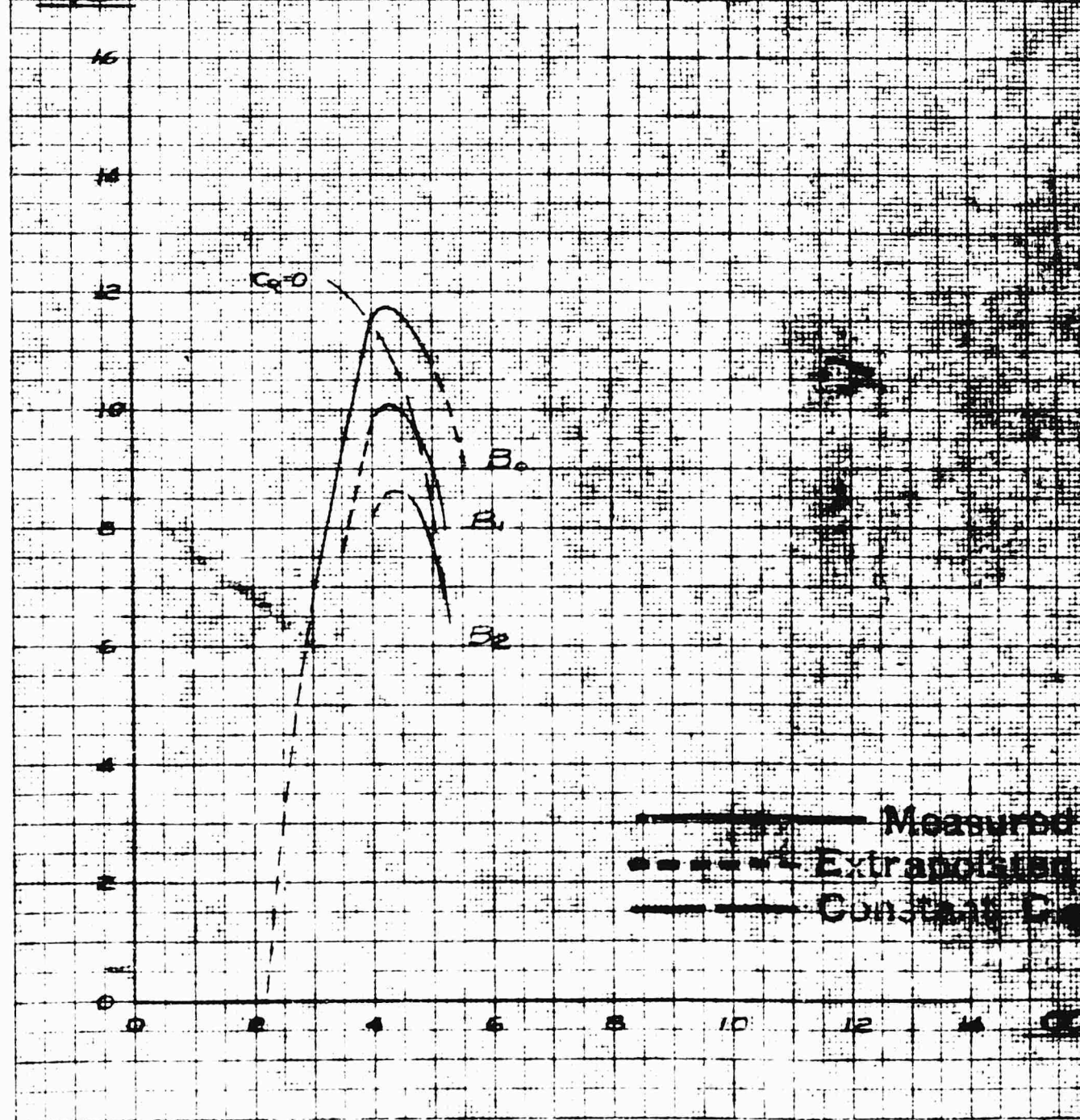
L/D vs OC

AXIAL OCTAG TESTS
WITHOUT HUB DRAG

2-1.5

1120

L/D



— Measured
- - - Extrapolated
— Constant D

KEUFFEL & ESSER CO.

No. 35614 Millimeters, 5 mm lines (scratched) and line heavy

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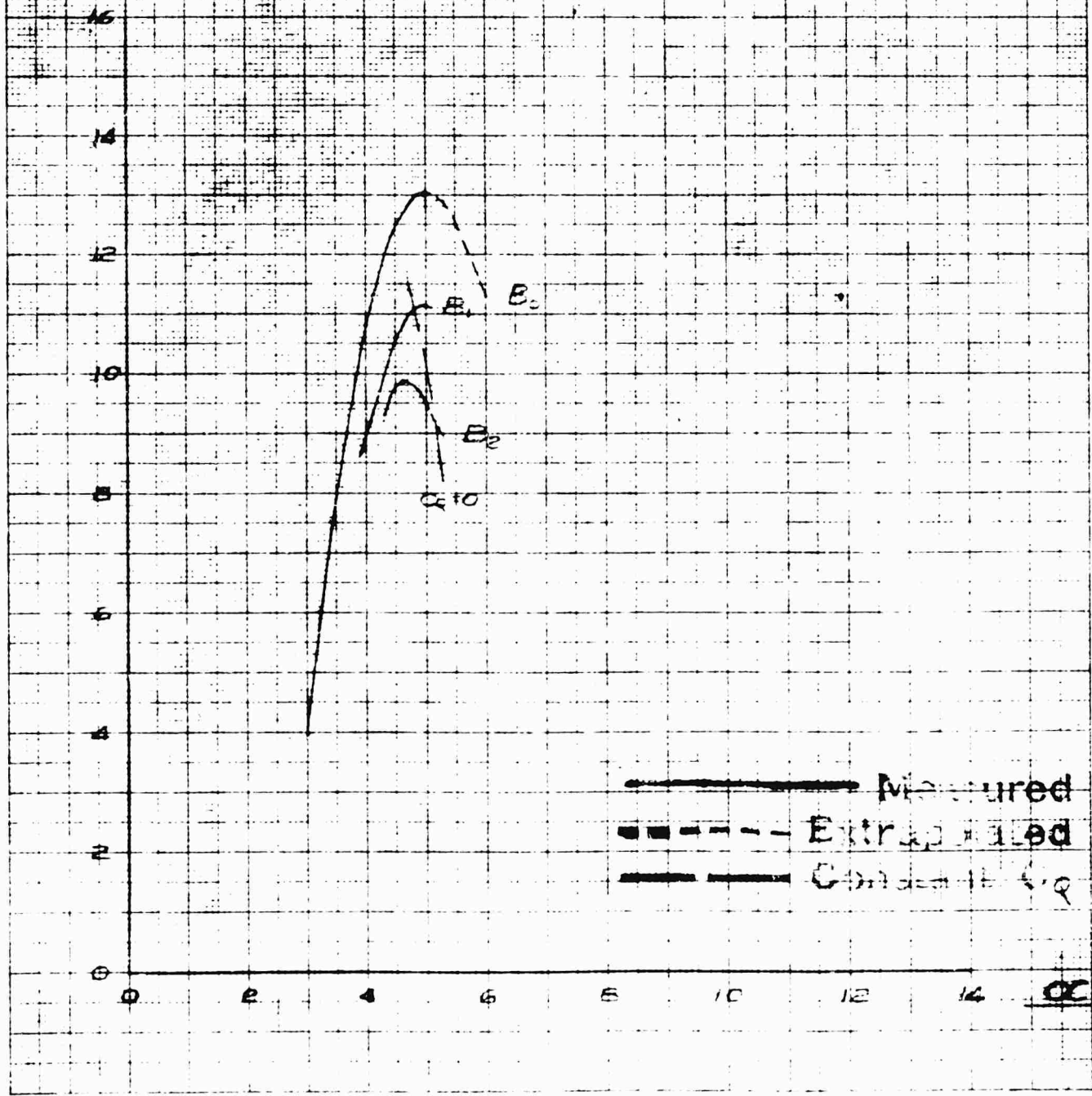
L/D vs OC

UNUAL OCT 49 TESTS
WITHOUT HUB DRAG

$\alpha = -1.5^\circ$

$M = 2.5$

L/D



KEUFFEL & ESSER CO.

No. 359 1.1 Millimeter, 5 mm lines, 300 lines, heavy

108

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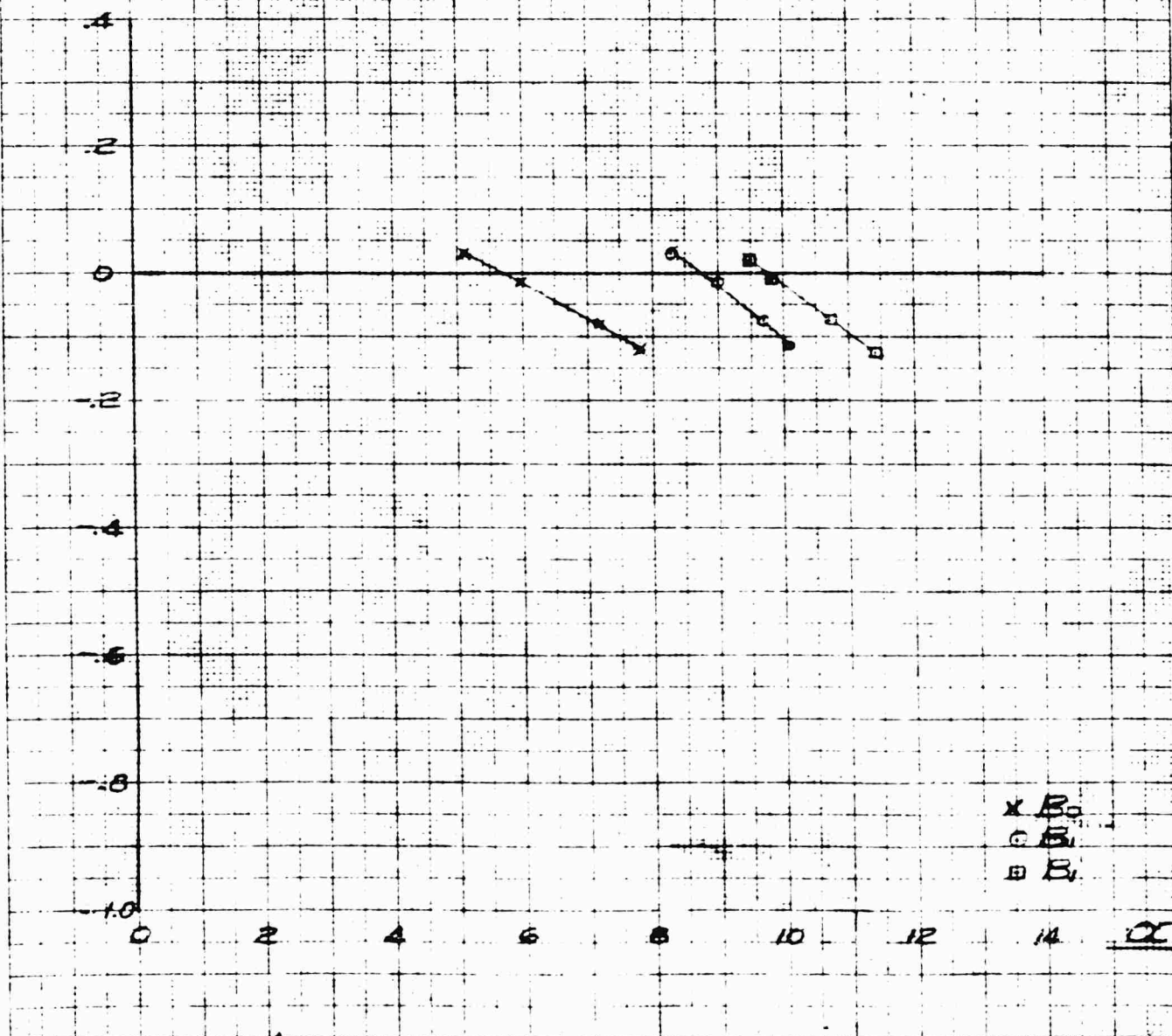
C_D vs α

UNVAL OCT 49 TESTS
WITHOUT HUB DRAG

$\alpha = -1.5^\circ$

$\mu = .5$

$10^3 C_D$



x B₀
o B₁
□ B₂

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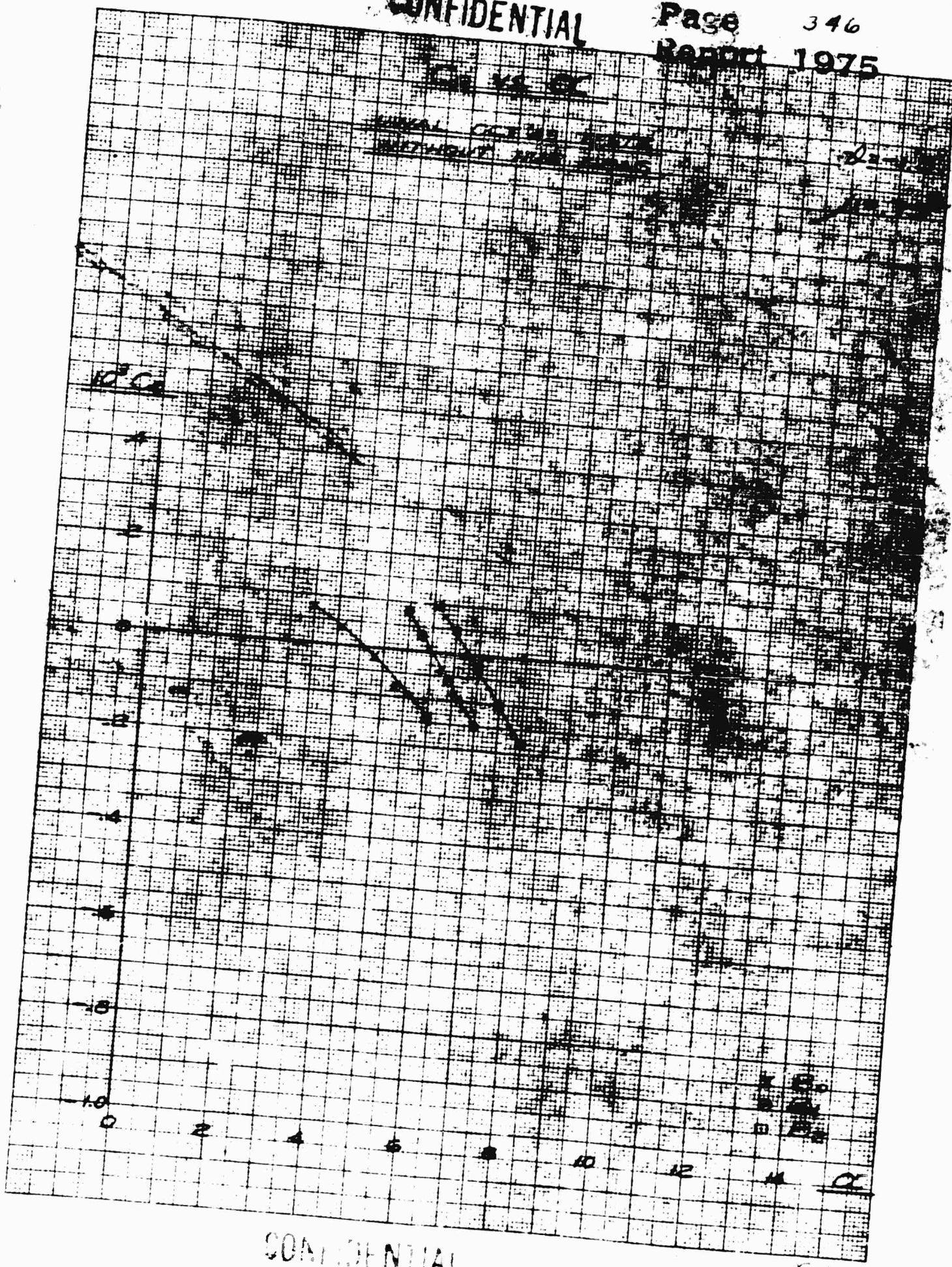
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CH VS CC

NORMAL OCCURRENCE
WITHOUT HAZARD

KEUFFEL & ESSER CO.

No 359 14. Millimeters, 5 mm lines accented on lines heavy.
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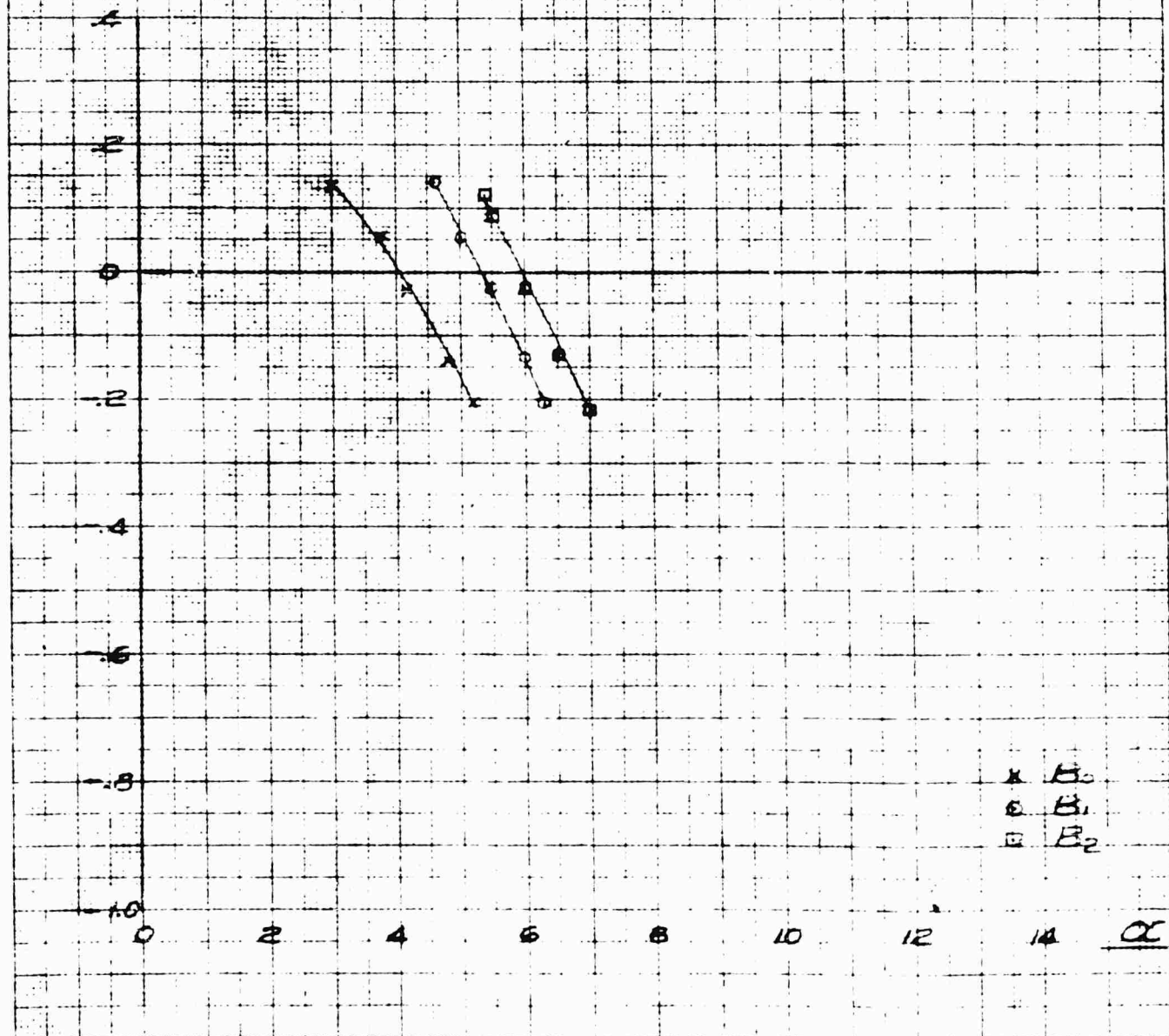
C_D vs α

FINAL OCT 29 TESTS
WITHOUT HUB DRAG

$\alpha = -1.5^\circ$

$\mu = 1.0$

$10^3 C_D$



x B_0
o B_1
□ B_2

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C_Q vs α

UNVAL OCT '49 TESTS
WITHOUT HUB DRAG

$\beta = -1.5^\circ$

$M = 1.25$

$10^3 C_Q$

4

2

0

-2

-4

-6

-8

-10

0

2

4

6

8

10

12

14

α

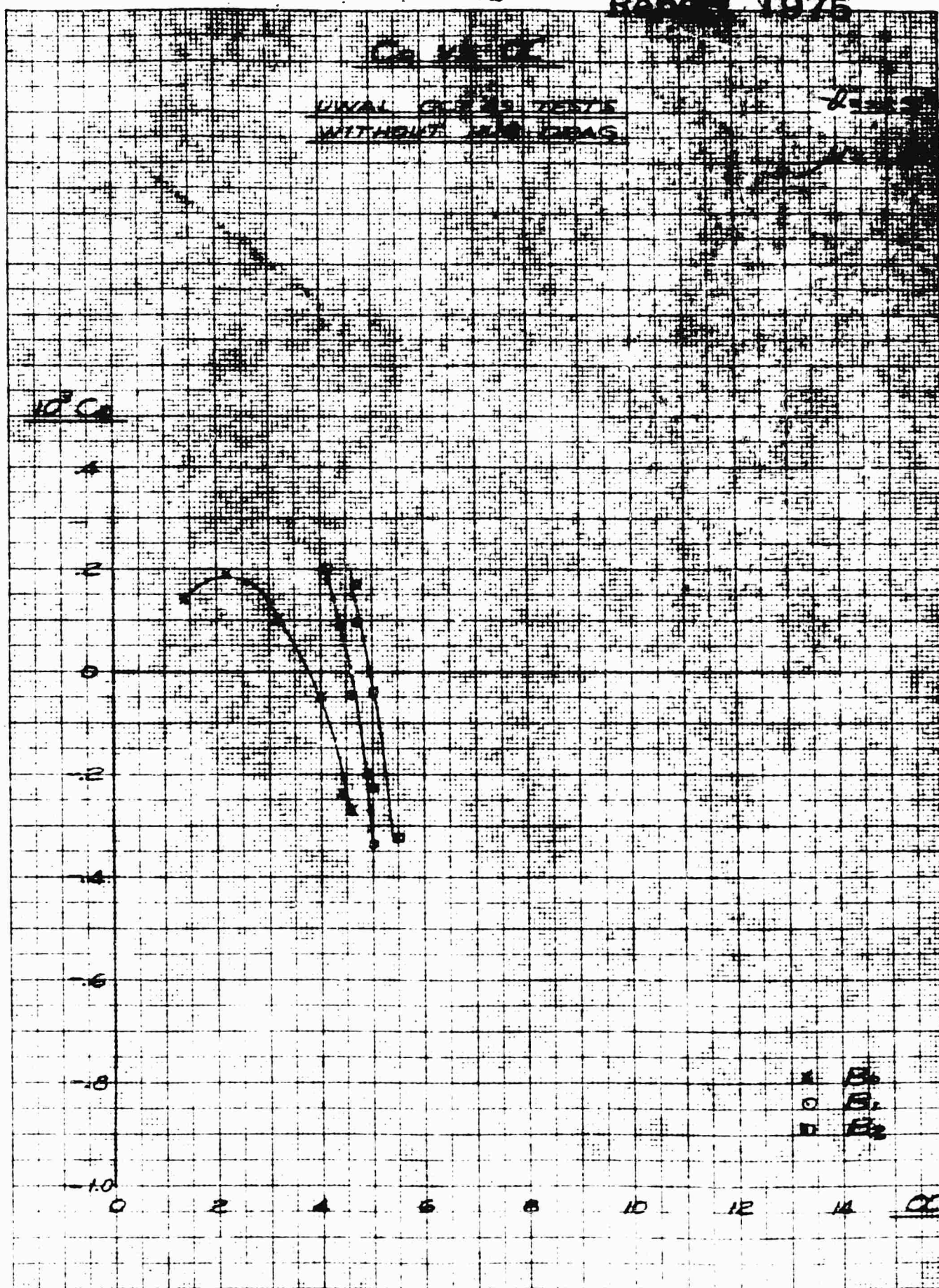
α_0
 α_1
 α_2

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1000 070 349
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UNION GLASS TESTS
 WITHOUT AIR DRAG



KEUFFEL & ESSER CO.

No. 319 14 Millimeters, 5 cm lines accented on lines heavy.

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 12-13-60

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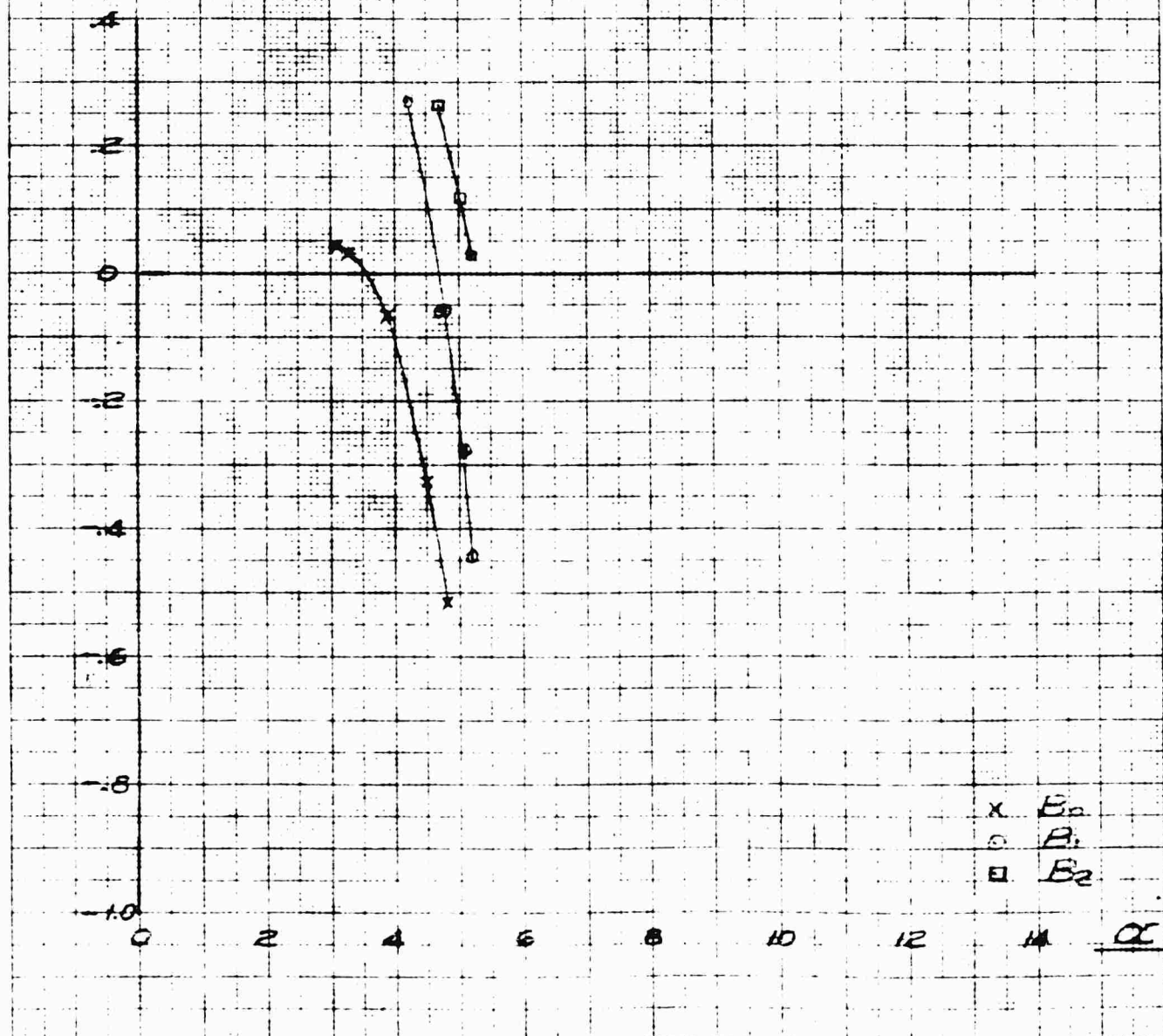
C_D vs α

FINAL OCT '49 TESTS
WITHOUT HUB DRAG

$\delta = -1.5^\circ$

$\mu = 0.0$

$10^3 C_D$



x E1
o B1
□ E2

KEUFFEL & ESSER CO.

No 359 14 Millimeters, 5 mm lines accented cm lines heavy

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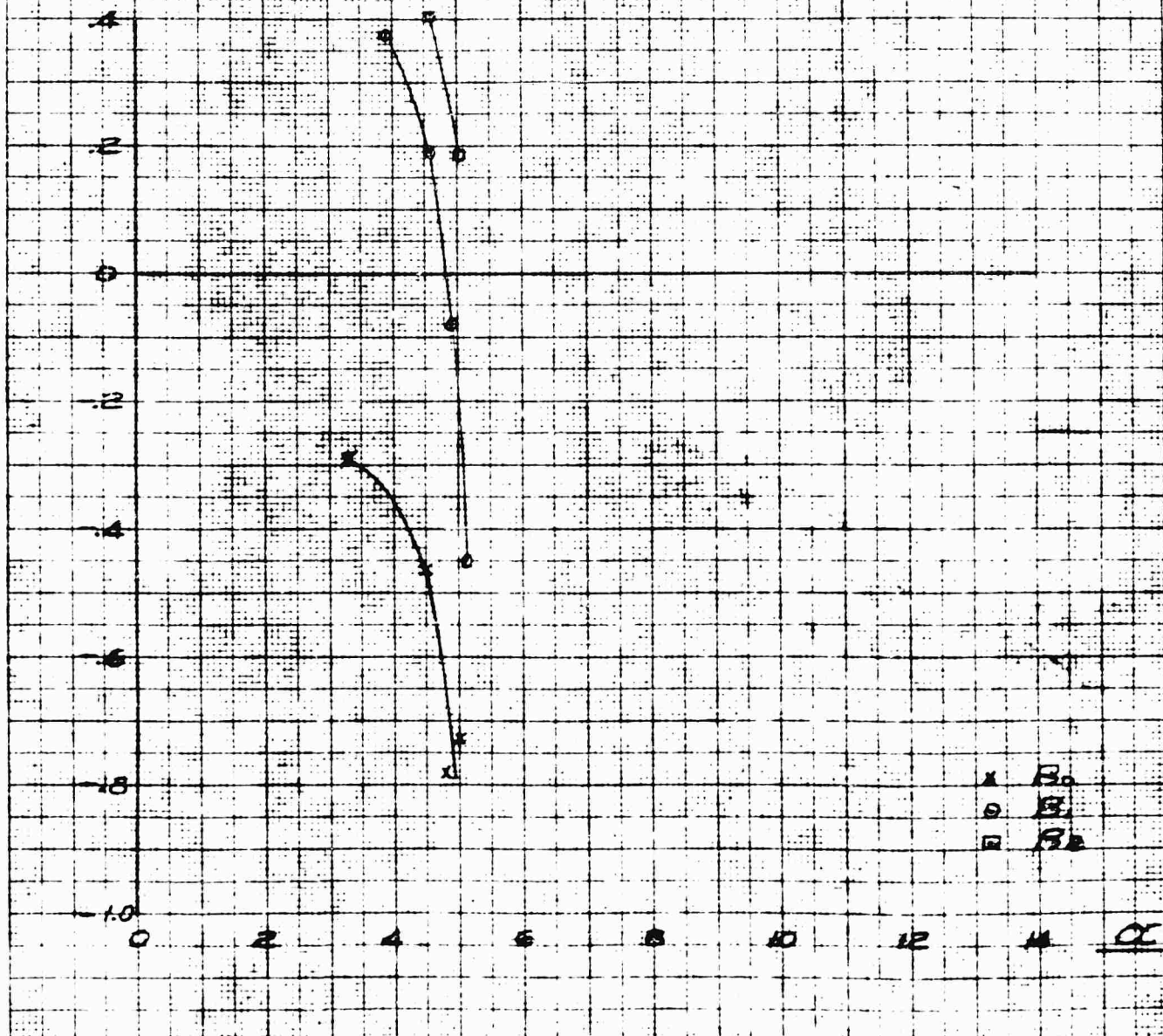
C_q vs OC

FINAL OCT 49 TESTS
WITHOUT HUB DRAG

$\epsilon = -1.5$

$\mu = 2.5$

$10^3 C_q$



KEUFFEL & ESSER CO.

No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy.

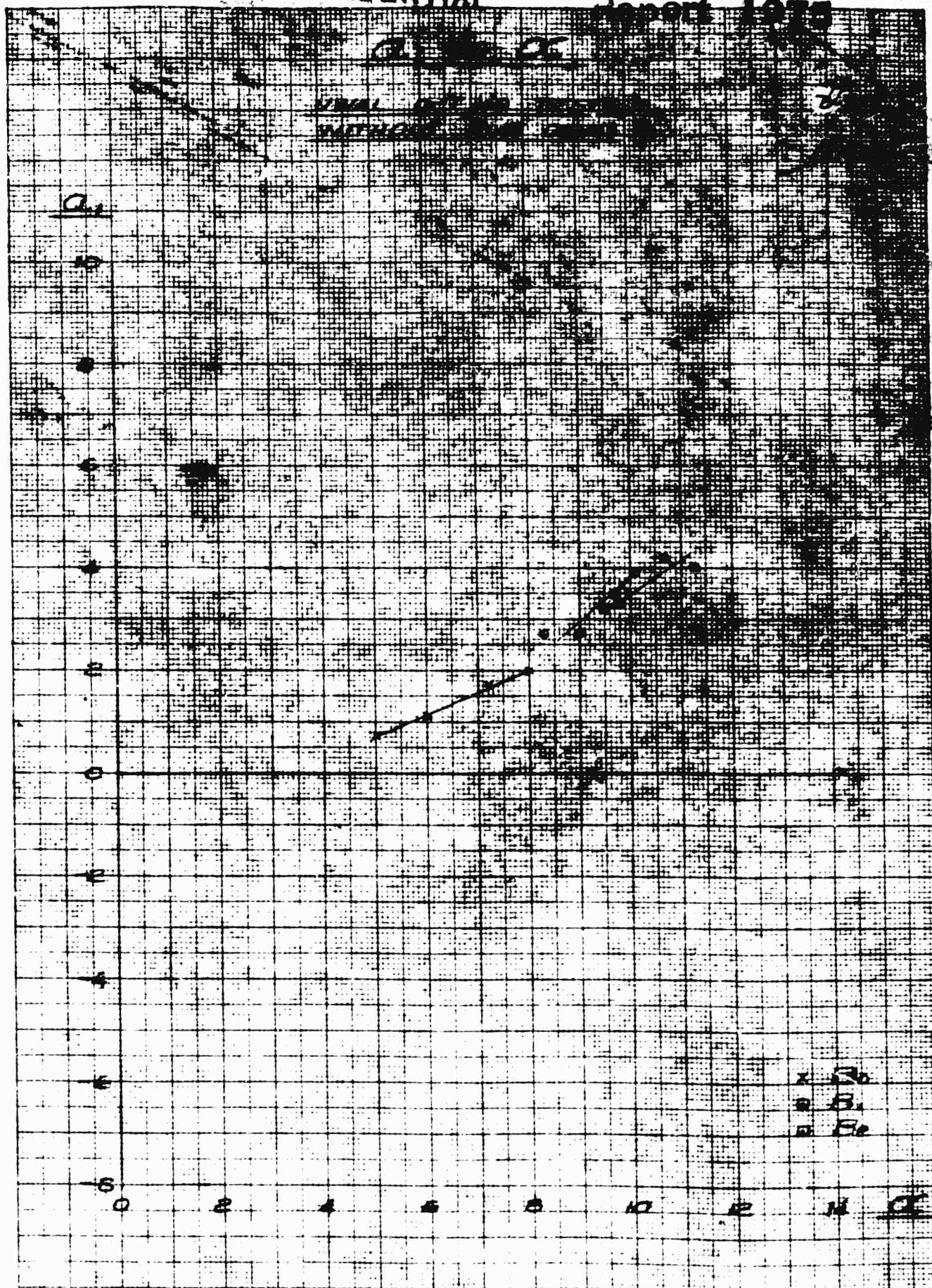
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No. 319-14. Millimeters, 5 mm lines accented on lines heavy.

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Q₁ VS Q₂

UWAL OCT 49 TESTS
WITHOUT HUB DRAG

$\psi = +1.5^\circ$

$\mu = .75$

Q₁

10

8

6

4

2

0

-2

-4

-6

-8

-10

2

4

6

8

10

12

14

Q₂

x B₀
o B₁
□ B₂

KEUFFEL & ESSER CO.

No. 359-14. Millimeters, 5 mm lines accented, on lines heavy

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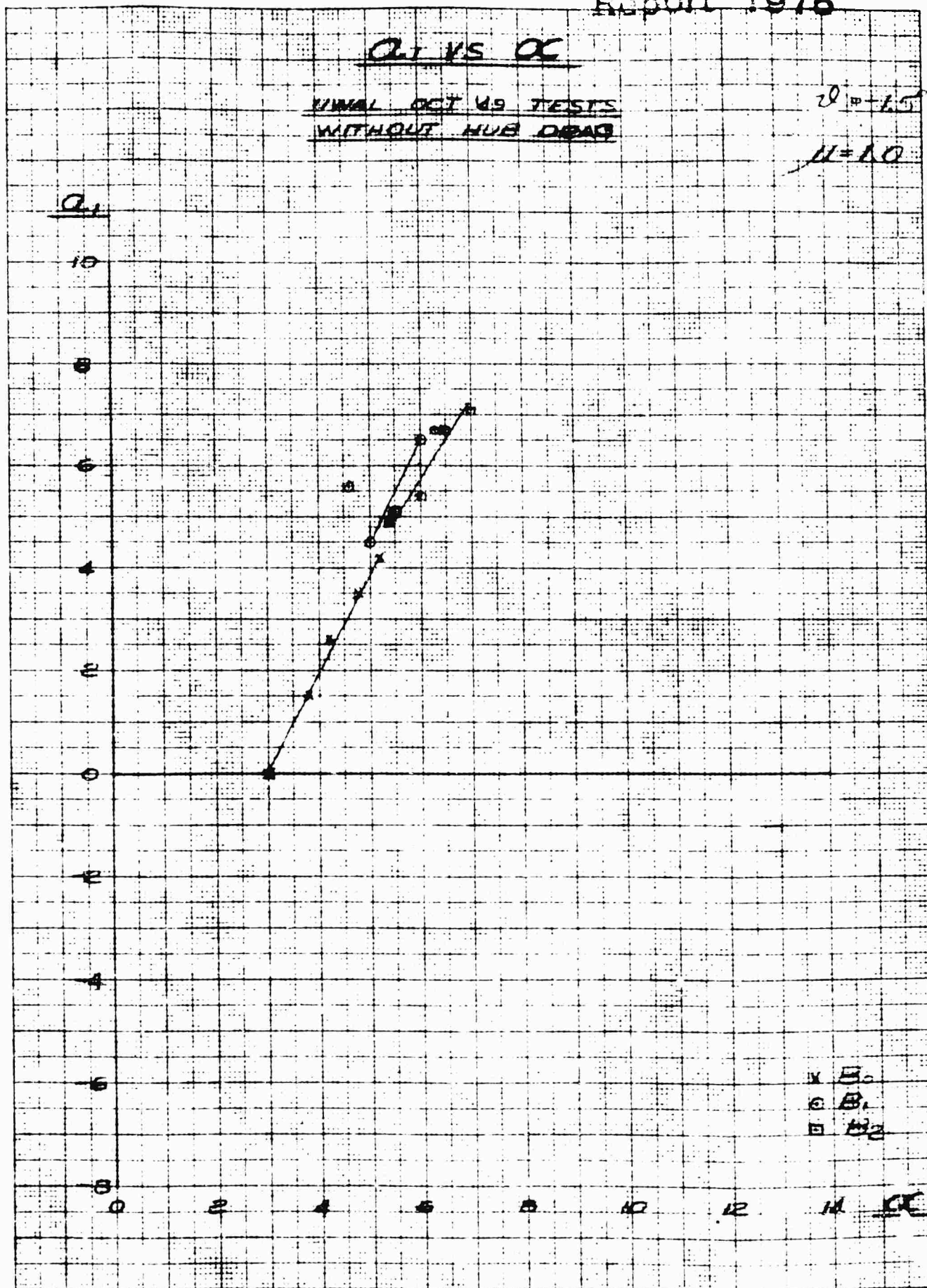
117

Q_L VS Q_C

UNUAL OCT 49 TESTS
WITHOUT HUE DEBS

$\sigma^2 = 1.5$

$\mu = 1.0$



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Q_L VS Q_C

FINAL OCT 49 TESTS
WITHOUT HUE DENS

$\delta = 1.5$
 $\mu = 1.25$

Q_L

10

8

6

4

2

0

-2

-4

-6

-8

0

2

4

6

8

10

12

14

Q_C

$\times B_0$
 $\circ B_1$
 $\square B_2$

K. CUFFEL & ESSER CO.

No. 359 14 Millimeters, 5 mm lines accented, dot lines heavy

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Q_1 vs Q_2

UNION OCT 40 1975
INSTRUMENT LINE 1000

8-100

10-10

Q_1

10

8

6

4

2

0

-2

-4

-6

-8

0

2

4

6

8

10

12

14

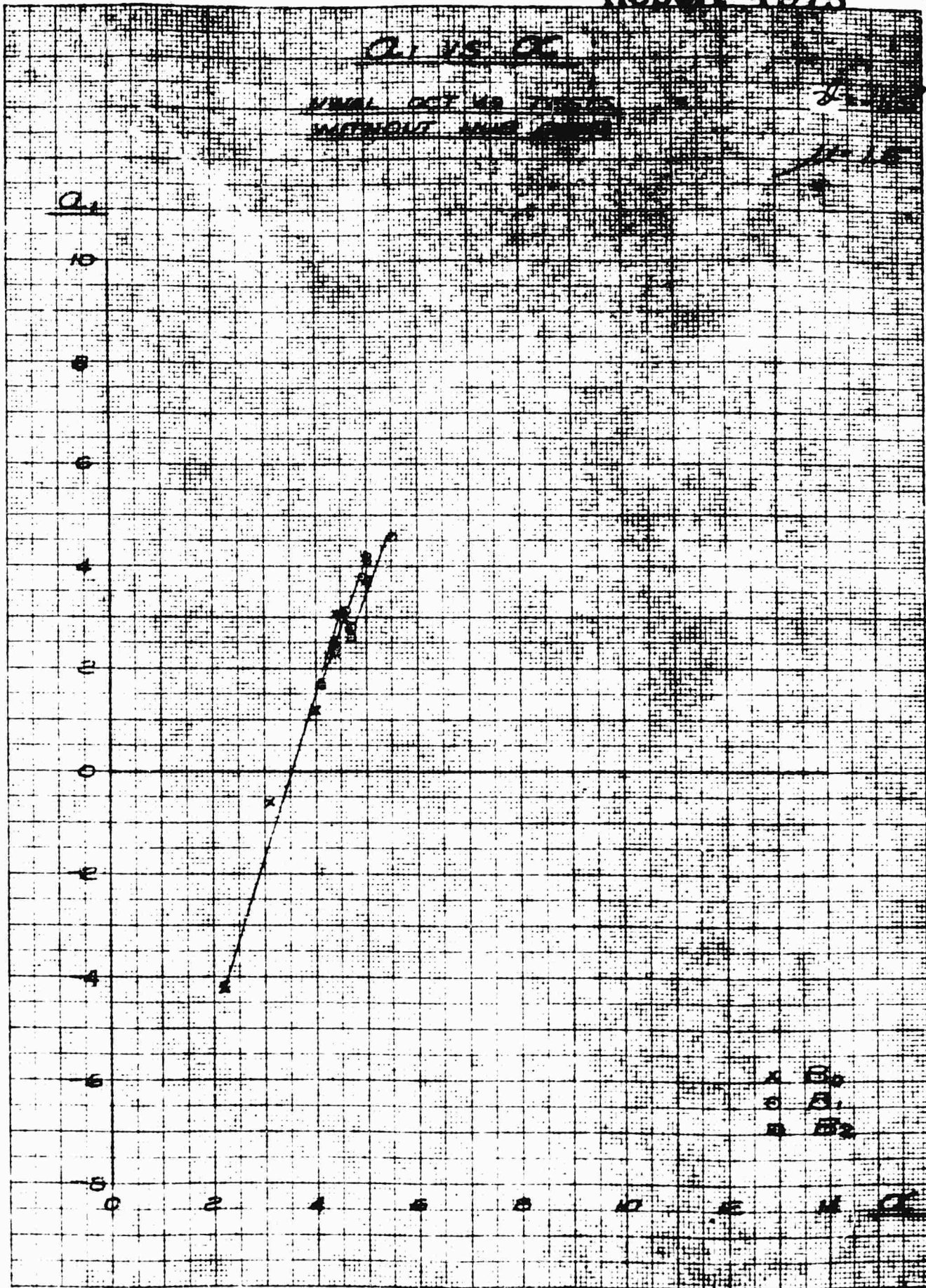
16

17-13 49

120

KEUFFEL & ESSER CO.

No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy



Q₁ VS Q₂

UNVAL OCT 49 TESTS
WITHOUT HUB DRAG

$\sigma = -1.5$

$\mu = 2.0$

Q₁

10

8

6

4

2

0

-2

-4

-6

-8

-10

2

4

6

8

10

12

14

16

X B₁
O B₂
□ B₃

KEUFFEL & ESSER CO.

No. 359-16. Millimeters, 5 mm lines accented, cm lines heavy
DATE 10-1-75

0000000000

1000000000

Q. VS. Q.

SMALL SIZE 49 TESTS
WITHOUT THIS DATA

Q. VS. Q.

Q. VS. Q.

